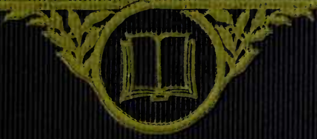
The Young Man and Civil Engineering

George Fillmore Swain



VOCATIONAL SERIES

EDITED BY

E. HERSHEY SNEATH, PH.D., LL.D., YALE UNIVERSITY

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GEORGE FILLMORE SWAIN

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"There be three things which make a nation great and prosperous: a fertile soil, busy workshops, and the easy conveyance of men and commodities from one place to another." BACON.

"Of all inventions, the alphabet and the printing press alone excepted, those inventions which abridge distance have done most for the civilization of our species." MACAULAY.

"What is vulgar, and the essence of all vulgarity, but the avarice of reward? 'Tis the difference of artisan and artist, of talent and genius, of sinner and saint. The man whose eyes are nailed, not on the nature of his act, but on the wages,—whether it be money, or office, or fame,—is almost equally low." EMERSON.

EDITOR'S PROSPECTUS

One of the most important decisions a young man is called upon to make relates to the determination of his life-work. It is fraught with serious consequence for him. It involves the possibilities of success and failure. The social order is such that he can best realize his ends by the pursuit of a vocation. It unifies his purposes and endeavors — making them count for most in the struggle for existence and for material welfare. It furnishes steady employment at a definite task as against changeable effort and an unstable task. This makes for superior skill and greater efficiency which result in a larger gain to himself and in a more genuine contribution to the economic world.

But a man's vocation relates to a much wider sphere than the economic. It is intimately associated with the totality of his interests. It is in a very real sense the center of most of his relations in life. His intellectual interests are seriously dependent upon his vocational career. Not only does the attainment of skill and efficiency call for the acquisition of knowledge and development of judgment, but the leisure that is so essential to the pursuit of those intellectual ends which are a necessary part of his general culture is, in turn, dependent, to a considerable extent, upon the skill and efficiency that he acquires in his vocation.

Nor are his social interests less dependent upon his life-work. Men pursuing the same calling constitute in a peculiar sense a great fraternity or brotherhood bound together by common interests and aims. These condition much of his social development. His wider social relationships also are dependent, in a large measure, on the success that he attains in his chosen field of labor.

Even his moral and spiritual interests are vitally centered in his vocation. The development of will, the steadying of purpose, the unfolding of ideals, the cultivation of vocational virtues, such as industry, fidelity, order, honesty, prudence, thrift, patience, persistence, courage, self-reliance, etc.— all of this makes tremendously for his moral and spiritual development. The vocationless man, no matter to what class he belongs, suffers a great moral and spiritual disadvantage. His life lacks idealization and is therefore wanting in unity and high moralization. His changeable task, with its changeable efforts, does not afford so good an opportunity for the development of the economic and social virtues as that afforded the man who pursues a definite life-work. It lacks also that discipline — not only mental, but moral — which the attainment of vocational skill and efficiency involves.

But notwithstanding the important issues involved in a man's vocational career, little has been done in a practical or systematic way to help our college young men to a wise decision in the determination of their life-work. Commendable efforts are being put forth in our public schools in this direction, but very little, indeed, has been done in this respect in the sphere of higher education. To any one familiar with the struggles of the average college student in his efforts to settle this weighty question for himself, the perplexities, embarrassment, and apparent helplessness are pathetic. This is due largely to his ignorance of the nature of the professions and other vocations which appeal most strongly to the college man. Consequently, he does not know how to estimate his fitness for them. He cannot advise to any extent with his father, because he represents only one vocation. Neither can he advise advantageously with his instructor for he, too, is familiar with the nature of only one profession.

For this reason, a series of books, dealing with the leading vocations, and prepared by men of large ability and experience, capable of giving wise counsel, is a *desideratum.* Such men are competent to explain the nature and divisions of the particular vocations which they represent, the personal and educational qualifications necessary for a successful pursuit of the same, the advantages and disadvantages, the difficulties and temptations, the opportunities and ideals; thus, in an adequate way, enabling the student to estimate his own fitness for them. They are also able to make valuable suggestions relating to the man's work after he enters upon his vocation.

Fortunately, in the present Series, the Editor has been able to secure the services of some of the most eminent experts in the country to prepare the respective volumes — men of large knowledge and experience, who have attained wide recognition and genuine success in their "callings." It is a pleasure to be able to place at the command of the many thousands of students in our American colleges the wise counsel of such experienced and distinguished men.

The "Vocational Series" will consist of twelve books written by representatives of different vocations, as follow:

1. The Young Man and the Law
   Hon. Simeon E. Baldwin, LL.D., Professor of Law, Emeritus, Yale University, ex-Governor and ex-Chief Justice of Connecticut
2. The Young Man and the Ministry
   Rev. Charles R. Brown, D.D., LL.D., Dean of the School of Religion, Yale University
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12. The Young Man and Government Service
   Hon. William Howard Taft, D.C.L., LL.D., ex-President of the United States, and Chief Justice of the United States Supreme Court

E. HERSHEY SNEATH.

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THE YOUNG MAN AND CIVIL ENGINEERING

CHAPTER I

INTRODUCTION

The field of engineering is so large, and its extent and limitations so little understood by the layman, that it is necessary at the outset to consider briefly the history of engineering and of the development of its various branches, in order that the reader may clearly perceive the proper meaning of the term "engineering," as well as of the narrower terms "civil engineering," "mechanical engineering," etc.

Engineering may perhaps be most briefly and at the same time most broadly described as the science and art of construction. Whoever constructs a thing, whether it be a bridge, a railroad, a steam engine, or a watch, is in the broadest sense an engineer. But there are obvious limitations and extensions of this definition, and these, as we shall see, lead to a more accurate definition. Engineering involves not merely manual or mechanical skill, but intelligent application of the laws of nature. Something more is required than mechanical proficiency in the use of tools or materials. The man who runs the engines in a mill, or the workman who fashions the parts of a locomotive, is not an engineer in the true sense. A knowledge of the reasons *why* certain mechanical operations have to be performed, and an *intelligent* adaptation of the laws of nature to the attainment of those ends, is necessary, and this involves the distinction between an art and a science.

A science teaches us to *know* and an art to *do*. A scientific man studies the reasons for things, investigates the laws of nature, and designs the means of adapting them to the end in view. The merely mechanical routine work of performing the operations necessary for the production or construction of the object or agency desired, is not engineering. A skilled mechanic, therefore, is not an engineer; neither is a skillful roadmaster of a railroad, though he superintends the laying and maintenance of the track; unless these men, in addition to being skilled in *doing*, are also skilled in *knowing*, so that they understand the reason why, and can adapt means to ends; modifying, if need be, their usual practice to meet particular emergencies.

In a similar manner, the scientist who, in the solitude of his study or laboratory, investigates the laws of nature, and perhaps discovers new ones, is not necessarily an engineer, unless he has the capacity of also showing how his discoveries may be made useful, though perhaps he may not himself have the mechanical skill necessary to put them into actual use, or to fashion the tools or instruments necessary for that purpose. An art, therefore, is, or should be, founded upon a science, the science teaching what to do, how to do it, and why, while the art develops the specific means of accomplishment.

Engineering is, therefore, both a science and an art. The engineer must know and must also be able to do. The important thing is the knowing, or the science. The engineer may not actually *do* a great deal with his hands, but he must at least know how to do it, should it be necessary; and, strictly speaking, he is not an engineer unless he is engaged to some extent in actually doing, whether with his own hands or by directing the hands of others. In a similar manner, the mechanic who is skillful with his hands, if he also knows the scientific principles governing the things which he does, and is able to coördinate intelligently the science and the art, may not be denied the title of engineer, provided he actually does use science and is not merely a workman, even a skillful one. The work of the engineer, therefore, involves the command and use of principles, and the ability to apply them in a way which will lead to the definite construction of some work. The engineer is not a mere mechanic or workman, though a mechanic or workman may well have the capacity to become an engineer if opportunity is offered.

What we know as the "learned professions" are those in which brain work is necessary and not merely skill. Engineering, therefore, should rightly be considered as one of the learned professions and not merely an art, since it requires for its exercise a knowledge of the laws of nature, and their application.

The profession of engineering is as ancient as any of the occupations of man. No doubt from the earliest times man has been subject to disease, and the *healing art* in more or less crude or imaginary form has long been practiced; man, naturally a quarrelsome animal, has also from the earliest time engaged in disputes with his neighbor, and in more or less imperfect form, the *law* has long had to be administered. Once more, from the most primitive times, man has realized the presence of some supernatural power which the *priest*, if only under the title of "medicine man," has endeavored to propitiate. But clearly, man has always required water and food, and has dug wells and employed crude means for raising water and for growing crops. He has also in the earliest stages of civilization required some sort of shelter and made use of some of the laws of nature for purposes of offense and defense, and for the fashioning of weapons, tools, and implements, even before the principles of law were formulated and perhaps before anything was known or even imagined with reference to the healing art; so that the engineer and architect (who so far as his work is constructive and not wholly artistic is also an engineer) may fairly claim that their profession is as old as any.

In the Lake Dwellers' village of Wangen, in Switzerland, fifty thousand piles are said to have been driven into the bed of the lake, to support the dwellings. This was in the Late Stone Age, between 10,000 and 3,000 years B. C. In Egypt, the pyramids were built about 2,900 years B. C., and great mechanical skill must have been possessed by the builders in quarrying, transporting, and raising the immense blocks of stone that were used. Buckle, quoting from Diodorus, says that "to build one of the pyramids required the labour of 360,000 men for 20 years," and that 2,000 men were occupied for three years in carrying a single stone from Elephantine to Sais. A little later, but fully 4,000 years ago, the Egyptians anticipated the construction of the Suez Canal by building a canal from the head of the Red Sea or Gulf of Suez westward to the easternmost branch of the Nile, so that vessels of that time could pass from the Mediterranean to the Red Sea by this route; and this work is said by Buckle to have cost the lives of 120,000 Egyptians. Thus early were accomplished engineering works which to-day would be called great, though done with a prodigal waste of human life and labor. The wonder is, however, that they could have been accomplished at all, considering the primitive state of scientific knowledge.

Many people, even those well informed, appear to have the idea that engineering is not a profession in the proper sense of the term, and that the engineer is neither a scientist nor professional man, nor yet a business man, strictly speaking, but that he is something betwixt and between, perhaps more nearly a mechanic. According to the dictionary, a profession is defined as "A vocation in which a professed knowledge of some department of science or learning is used by its practical application to the affairs of others, either in advising, guiding, or teaching them, or in serving their interests or welfare in the practice of an art founded on it. Formerly, theology, law, and medicine, were specifically known as *the professions;* but as the applications of science and learning are extended to other departments of affairs, other vocations also received the name. The word implies *professed attainments in special knowledge*, as distinguished from mere skill; a practical dealing with affairs, as distinguished from mere study or investigation; and the application of such knowledge to the uses of others as a vocation, as distinguished from its pursuit for one's own purposes." According to this definition engineering is clearly both a science and an art.

Up to the present time the art involved in the work of engineering has probably been more recognized than the science. The engineer has been considered rather a builder than a scientific man, pursuing an occupation or avocation, rather than a profession. As civilization developed, the work of the engineer and builder developed correspondingly. The Assyrians and Babylonians built canals and bridges; the inhabitants of India, great reservoirs; the Egyptians, pyramids; the Romans, roads, bridges, aqueducts, baths, and other important works, many of them of great extent, and requiring unusual skill. The builders of these works were engineers.

During the early development of the profession, engineering came to be divided into two kinds, *civil* and *military;* the latter being concerned with the construction of fortifications, and with all other means of defense and offense; while civil engineering included all other applications of the constructive art. The uncertainties, however, with regard to the precise meaning of the term civil engineering, and the desirability of having it accurately defined, led the Council of the Institution of Civil Engineers of Great Britain on December 29, 1827, to pass the following resolve:

> "RESOLVED, That Mr. Tredgold be written to, requesting him to define the objects of the Institution of Civil Engineers,* and to give a description of what a civil engineer is, in order that this description and these objects may be embodied in a petition to the Attorney General in application for a charter."

At the following meeting of the Council on January 4, 1828, a communication from Mr. Tredgold was read and entered in the Minutes, bearing the title "Description of a Civil Engineer, by Thomas Tredgold, Hon. M. Inst. C.E.," as a result of which the charter of the Institution described the profession of the civil engineer as "the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and ex-

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* The Institution of Civil Engineers of Great Britain was founded in 1818, and incorporated by Royal Charter in 1828; the Institution of Mechanical Engineers was formed nineteen years later, with George Stephenson as the first President.

change; and in the construction of ports, harbors, moles, breakwaters and light houses; and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns."

Tredgold's definition of Civil Engineering as "the art of directing the great sources of power in nature for the use and convenience of man," is the definition still generally given. It is suggestive in various ways; it emphasizes, as has been done on a previous page, that engineering properly involves the *application* of the laws of nature. It also involves a concrete application of those laws "for the use and convenience of man" and not merely for abstract or useless purposes. It may be criticized, however, in defining engineering as an art. It would perhaps be proper to consider engineering to be an art founded upon some branch or branches of science, such as the science of mechanics or of physics or of chemistry, but the art and the science cannot always be clearly differentiated; it is not easy to tell where the science ends and the art begins. If we adhere strictly to the conception that engineering is an art and therefore limited strictly to the doing, this would lead us to conclude that a man is only an engineer when he is executing the work, and that while he is designing it or studying the principles governing its design, he is a scientist. It seems more proper to consider engineering as both a science and an art, and not simply as an art depending upon a science.

Furthermore, engineering is concerned not only with directing the sources of *power* in nature, but in utilizing and applying all the laws of nature and all the materials of the external world. Tredgold's definition was formulated at a time when the minds of engineers were filled with the new discoveries relating to power, which will hereafter be briefly referred to—with the steam engine, the steam boat, and the steam locomotive. The subject of power was, therefore, foremost in men's minds, and it is natural that this should have been emphasized in the definition.

Recently, the late Mr. Henry G. Stott, in his address as President of the American Institute of Electrical Engineers, proposed as an improvement upon Tredgold's definition, the following:

> "Engineering is the art of organizing and directing men, and of controlling the forces and materials of nature for the benefit of the human race."

This definition, however, is also incomplete in that it terms engineering an art. Furthermore, it would apply the term to any activity in organizing and directing men, such for instance, as in military or political operations, and while this use of the term is often suggested, as when we speak of "engineering a deal," such use is a corruption or slang expression. Furthermore, neither of the definitions quoted puts any emphasis on one of the most important functions of engineering, namely, the regard for economy. The organizing and directing of men does not seem to be properly engineering, though we may sometimes refer to it as such; nor should a clumsy and wasteful and useless application of the laws of nature be termed engineering, though perhaps we should recognize it as simply bad engineering. A man, who by no stretch of the imagination could be called an engineer, might, if he were given sufficient time, men, and money, construct works similar to or identical with some of those built by engineers. It is, of course, plain there will always be differences of efficiency between engineers, and both good and bad engineering, and yet it would seem that some emphasis should be laid upon economy. Indeed, an engineer has been wittily defined as a man who does with one dollar what any fool can do with two.

James Nasmyth, the great English engineer and inventor, defined engineering as "common sense applied to the use of materials."

In view of the above considerations the following definition is suggested, namely:

Engineering is the science and art of applying, economically, the laws, forces, and materials of nature, for the use, convenience, or enjoyment of man.

The proper practice of engineering clearly requires both knowing and doing, and it is this combination, together with the character of the work done by the engineer, that leads to the somewhat peculiar position of the profession. It is not, of course, an art in the sense of being one of the fine arts. The engineer, as such, has little or nothing to do with questions of beauty, although every member of the profession should aim to possess such knowledge of the canons of beauty as to lead him to construct works which are not only useful, but beautiful as well, with due regard to economy. The engineer must know the laws and forces of nature and the properties of materials, and must be able to apply them economically. The laws and forces of nature with which he must be familiar, will depend upon the specific branch of the profession which he practices. Tredgold, after giving his definition of civil engineering, in which he specified many branches of the profession, concluded with the prediction that the extent of the profession was "limited only by the progress of science, and that its scope and utility would be increased with every discovery in philosophy, and its resources with every invention of the mechanical or chemical arts, since its bounds are unlimited and equally so must be the resources of its professors."

This prediction has been abundantly justified. Since Tredgold's time great fields, then unsuspected, have been added to the profession of engineering, resulting in the development, from the original root of civil engineering, of numerous branches, each of which is now a profession by itself. A knowledge of these developments, as well as of some which took place even before Tredgold's definition was formulated, is essential in order that the reader may clearly see the relation of civil engineering to other branches of the profession.

Up to nearly the end of the eighteenth century the *sources of power* in nature were little understood and could be utilized only to a comparatively small degree. Up to that time engineering comprised mainly the construction of roads, canals and bridges, the improvement of harbors, river works, the construction of docks, and the supplying of towns and cities with water. The state of the art only allowed of the construction of bridges of very short span, either of stone or wood, since iron had not yet been brought into use, and ferries were generally employed in crossing streams too deep for fording. The steam engine was known only in a very crude and uneconomical form; the weaving of cloth was almost all done by hand; there was little transportation except by sea; cities were not drained, or lighted by gas; the applications of electricity were, of course, unknown; navigation by water was entirely by means of sailing vessels or with oars; and the only form in which iron was used to any large extent was in the form of cast iron.

But before the end of the eighteenth century there came a remarkable series of mechanical inventions—the spinning jenny by Hargreaves, the spinning frame by Arkwright, the mule by Crompton, the power loom by Cartwright, the modern steam engine by Watt, the puddling process for making wrought iron by Cort, and others. These were followed, in the first third of the eighteenth century, by the development of the steam locomotive by Stephenson, of the steamboat by Fulton, by the inauguration of the era of railroads, beginning for all practical purposes with the victory of the "Rocket" in the competition at Rainhill in 1829, and by further great improvements in manufacturing, and in the production of iron and steel.

It was just at this time, when the minds of all were filled with the inventions of Watt and of Stephenson, that Tredgold gave his definition, clearly showing the tremendous influence held at that time by the subject of *power*. These great developments much enlarged the field of engineering, and gave birth to a new class of engineer—the railroad engineer. They led also to the differentiation of the mechanical engineer from the civil engineer. Since that time the mechanical engineer has claimed as his special field the development and use of power in all its forms, including the generation of power from the combustion of fuel or the flow of water, by means of the various types of engines and water wheels, the transmission of that power from point to point by belting, shafting or other means, and the utilization of that power by machinery. There is hardly a field of human industry, therefore, which is not dependent upon the mechanical engineer, because all manufactured articles depend upon power in some application, and upon machinery operated by power.

The field of the modern mechanical engineer, however, not only covers the department of power and its applications—in manufacturing, in the steam locomotive, in the steamship—but it is also held to include the construction of mills, and all applications of steam and heat such as heating, ventilation, lighting, and so on.

But notwithstanding the differentiation from it of the field of the mechanical engineer, the field of the civil engineer was itself enlarged by the progress of science and invention. The great impetus given to manufacturing rendered necessary the distribution of the raw material and of the manufactured products. Transportation engineering was enormously increased in its scope and the new profession of the railroad (civil) engineer was brought into existence. Roads, railroads, canals, harbors and docks, were built with unexampled rapidity, and river improvements were extensively carried on. At this time the increasing use of canals gave occasion for the celebrated remark of Brindley, the great canal engineer of England, himself an untutored genius, who, when asked what the use of a river was, replied "to supply canals with water." At the same time the economical production of wrought iron rendered possible the construction of bridges of considerable span.

By this time had begun one of the greatest sociological movements which characterizes the present time, namely, the increasing congregation of people in cities. At the beginning of the nineteenth century only three per cent. of the population of the United States lived in cities, while at the present time the urban population is over fifty per cent. of the total. This phenomenon, during the last half of the century just passed, has led to the differentiation of another field of engineering, namely, that of the sanitary engineer, whose specific province it is to deal with the problems of water supply, drainage, the disposal of refuse, the purification of water and sewage, the sanitation of dwellings, and the various other problems resulting from this congestion of population.

Improvements, also, in chemistry and in metallurgy, have given rise to still other distinct branches of engineering, namely, mining engineering and metallurgy, the scope of which it is not necessary here to sketch.

Again, the field of the mechanical engineer has during the past quarter of a century become subdivided, owing to the discoveries in electricity. Steam and water are no longer used simply to propel steam engines or water wheels, producing power to be used on the spot. Steam or other engines, and water wheels, now drive electric generators, the currents from which are transmitted long distances, sometimes as great as 200 or even 300 miles, by means of transmission wires, to be again transformed by electric motors and used for the production of light or for the operation of machinery. The telephone and the telegraph have been discovered, electric cars have replaced the horse cars, and the traffic of our steam railroads is in some cases being hauled by electric locomotives. Almost everything nowadays *is* done or *can be* done by electricity, even to preparing our food, washing our clothes and dishes, and heating our houses. The electrical engineer, with a field already so wide that it is divided into specialties, is a product of the last twenty-five years.

By the last third of the nineteenth century, therefore, there had grown out from the original stem of civil engineering, three professions so differentiated from it and from each other, that they have ever since been and are still regarded as separate professions, namely: (1) Mechanical engineering, (2) electrical engineering, (3) mining engineering and metallurgy. A fourth stem, namely, architecture, may be said to have been differentiated from civil engineering at a still earlier date.

These five professions are represented by the five great national engineering societies in the United States, namely:

(1) The American Society of Civil Engineers (Instituted Nov. 5, 1852).

(2) The American Society of Mechanical Engineers (Organized 1880, Incorporated 1881).

(3) The American Institute of Electrical Engineers (Organized 1884, Incorporated 1895).

(4) The American Institute of Mining Engineers (Organized 1871).

(5) The American Institute of Architects (Incorporated 1857).

These professions have many points of contact and cannot be sharply differentiated from each other. There are overlapping or twilight zones which may be considered to belong to either of two or more. In the last analysis, members of all these professions belong to the one great profession of engineering, but for practical purposes it is desirable and usual to consider them as distinct. Indeed, each of these professions has, with the development of science, become divided into a number of specialties. This is particularly true of civil engineering for, notwithstanding the differentiation from it of the fields of architecture, mechanical engineering, electrical engineering, mining engineering and metallurgy, the field of the civil engineer keeps on ever increasing in scope. Coasts have to be protected from the sea, swamp and marsh lands reclaimed, large areas irrigated by artificial means, requiring the construction of great dams, the storing of immense quantities of water and the distribution of that water by means of canals into the uplands. Novel problems of urban transportation present themselves and must be solved by the construction of subways and tunnels; great railroad terminals have to be provided; and towering sky-scrapers are constructed by the engineer, who here trenches upon the domain of the architect. Also the possibility of electrical transmission, and the increasing scarcity and waste of fuel, have increased enormously the importance and value of water powers. The question of the discharge of rivers, the means of increasing it, of storing it so as to make it more regular from month to month, thus avoiding the damage due to floods, and increasing the power during dry seasons, the construction of dams and of the various works incident to the development of water powers, all these, together with other problems, now constitute a separate field, that of the hydraulic engineer. Water, at once the most valuable and necessary of the gifts of nature, and at the same time an enemy to be dreaded and feared, must be controlled and governed, so that communities may be supplied adequately with this necessity of life and the power generated by the rivers turned to the service of man. The laws of water flowing in conduits, through pipes and in open channels must be studied and experimented upon, and the science of the laws of water—hydraulics—is steadily increasing in value and in importance.

Of recent years, in addition to the five main branches of the profession of engineering above enumerated, others may fairly be said to have been developed. The increase in transportation by sea, the use of steel ships, and the ever increasing size of vessels, has led to the profession of the naval architect, itself a large field, dealing with the applications of steel and other materials to the construction of vessels. Another specialty of mechanical engineering is that of the marine engineer. The naval architect builds the vessels, the marine engineer equips them with machinery and provides them with ventilating and other apparatus necessary to fit them for use. Still another branch or specialty of mechanical engineering has been developed by the construction of large and high buildings, namely, the profession of the heating and ventilating engineers, which deals with the methods and means of heating and ventilating buildings of all kinds. Indeed, the architect may be said to produce the mere shell of a great building. The equipping it with machinery and apparatus for heating and ventilating, with elevators, water supplies, plumbing, and fire protection, is a large problem in itself, and belongs to engineering rather than to architecture.

Finally, investigations in the various fields of applied chemistry, as for instance in the production of gas and oil, in the manufacture of rubber goods, soap, glue and other materials too numerous to mention, have led in recent years to the formation of still another branch of the profession, namely, that of chemical engineering, which deals with the application of chemistry to the useful arts. To even enumerate the applications of this science would tax the patience of the reader.

From the above brief sketch it will appear that civil engineering is the parent stem which at first included all branches of the constructive art, with the exception of military engineering, which may perhaps be considered to be, in its objects, more destructive than constructive; that from this parent stem four to six new branches may be said to have grown, which now constitute professions in themselves and are not the subject of further consideration, except incidentally, in this book. What remains in the field of civil engineering is, however, even now much larger than it was in Tredgold's time, and it is continually growing as new applications of science are discovered and new lines of practice are founded upon them.

In its restricted meaning, civil engineering may be said to include the following branches, although some of these specialties may be claimed to be entitled to rank as separate professions:

(1) Surveying and Geodesy, which deals with the measurement and delineation of large or small portions of the earth's surface and the objects found thereon.

(2) Railroad Engineering, which deals with the location and construction of railways, and their maintenance and operation so far as engineering principles are concerned.

(3) Highway Engineering, which deals with the location, construction and maintenance of highways, including city streets and pavements.

(4) Hydraulic Engineering, which deals with the laws governing the flow of water in all kinds of channels, and with the principles governing the flow of water upon the surface of the earth, both in surface and underground channels; with the discharge of rivers, the methods of controlling it and of protecting banks and preserving navigable channels; with the location and construction of dams and their appurtenances, for retaining bodies of water, for the water supply of communities and for the production of power; with the construction of canals, harbors, light houses and other works in which the control of water is the main problem. This branch of the subject includes what is known as canal, river, and harbor engineering, water power engineering, irrigation engineering, and water-supply engineering.

(5) Sanitary Engineering, which deals with problems relating to the protection and preservation of the health of communities, involving many aspects of water supply engineering; the sanitation of dwellings and other buildings; the sewerage of cities and towns; the drainage of land; the disposal of sewage, refuse, garbage; and in general with works for the preservation of the public health.

(6) Structural Engineering, which finds its application in all of the other branches, and which deals with the details of design and construction of fixed structures of all kinds, and their foundations, such as bridges, roofs, buildings, dams, retaining walls, tunnels, subways, and many other types of fixed structures.

To these may be added municipal engineering, which is a combination of several of the above; and the newer branch of valuation of properties.

Having attempted to give some idea of what civil engineering is, it is desirable to call attention to what it is not. The word engineering is often used very vaguely and is made to include occupations which should be designated by another title. The man who runs a locomotive, or who superintends a stationary engine plant, is frequently termed an engineer, though seldom a civil engineer. Strictly speaking, this designation is a misnomer. Such a man should be termed an engine-man, for while it is undoubtedly true that many men of this class have acute common sense and thorough knowledge of the machinery entrusted to their charge, both as regards its construction and its operation, so that they may be in fact intellectually and technically superior to many men who claim the title of engineer, yet there should be a distinction made between the man whose business it is to design as well as to construct, who understands the science as well as the art, and the man whose occupation it is simply to superintend the running of a machine or a plant. Similarly, a plumber sometimes styles himself a sanitary engineer, although his work is purely mechanical and concerned with the fitting together of the various pieces of apparatus which are involved in the plumbing or water supply of a building, and he may be entirely ignorant of the scientific principles involved, and entirely incapable of designing the plant which he puts together.

The lines of demarcation between the above branches of the profession are more or less indefinite and indistinct, as will be fully pointed out in later pages, just as the line of demarcation between civil engineering and mechanical engineering, electrical engineering, architecture, or even economics, is more or less indistinct.

A little reflection upon the foregoing review will make clear the enormous extent of the field of engineering as a profession, and even of what is still left as properly comprised in the province of civil engineering; and will probably justify the statement that this field is more extensive than that of any of the three professions which from time immemorial have been known as the learned professions. The different branches of the engineering profession differ from each other to such an extent that in some cases they have little in common, except a knowledge of the general principles of physics, chemistry, mechanics, or other sciences. The profession of the physician, it is true, is divided into many specialties, but while the throat specialist deals with the throat, the heart specialist with the heart, and the stomach specialist with the stomach, they are all dealing with the human body, in which all parts and functions are closely interconnected. The lawyer, too, no matter which of the many specialties of the profession he pursues, is always dealing with the law and its administration. But even within the narrower field of civil engineering, the railroad engineer and the irrigation engineer, or the railroad engineer and the achitectural engineer, deal with the application of entirely different laws of nature and their work may have little in common. Assuredly, Tredgold was right when he said that the bounds of the profession are unlimited.

Attention has been called to the fact that, as civilization advances, the various branches of engineering developed, resulting in the differentiation of many specialties. It may, however, be fairly claimed that the development of engineering was not a *result* of the advance of civilization, but the principal *cause* of it. There has been much discussion by historians and sociologists as to the causes of the progress of civilization, and whether it has been due mainly to moral or to material advances. Those who are accustomed to look always at the moral aspect of phenomena, and who contrast the improved attitude toward moral questions which exists in general to-day, as compared with past centuries, are apt to believe that moral progress has been the main element in the progress of civilization; but when it is rememberd that in the teachings of the ancient Greeks, Romans and other peoples there may be found laid down as high standards of morality as those that are now recognized; that the moral teachings of the religions of the world to-day had their origins centuries ago; that human nature to-day, notwithstanding all these moral teachings, remains essentially the same as it has always been; and that in fact moral standards necessarily vary according to circumstances, such as time and place; it will probably be perceived that what we call progress in civilization has been mainly due to the advances in the applications of the laws of nature, that is, to the work of the engineer, and that any improvement in moral standards and ideals follows as a result of these advances.

No profession is, therefore, more important for the welfare of the human race than engineering, not even that of medicine, which has done so much for the alleviation of the physical suffering of mankind. None has done more to promote the well-being and to advance the best interests, material and moral, of the human family. Preëminent among the agencies which have been developed by the engineer and which have operated for this advancement, are the invention of the printing press and of the telegraph and the telephone, which provide the means of the registration, communication, and transmission of ideas; the development of transportation, by railroad, highway and steamship; and the various developments in manufacturing and industry which make possible the economic production of the fruits of the earth and the materials of mines and quarries, and their fashioning into forms serviceable for the use of man. It is these inventions and developments which have quickened the moral tone of mankind and led to such moral improvement as may have been achieved. They have made the whole world kin. An occurrence in almost any part of the world may now be made known everywhere within a few hours. The products of one land are spread broadcast. No nation is now isolated, but not only is it commercially in touch with the whole world, but its acts, good or bad, are quickly known, and arouse moral approbation or indignation, as the case may be.

The engineer is, therefore, the true civilizer of mankind or the advance agent of civilization. If all that he has accomplished in the last few centuries could be wiped out, what would remain of our civilization? That progress is primarily due to material and not to moral causes, is evident from the fact that even the advances due to the applied scientist do not prevent the commission of grievous crimes, but are even seized upon and made to serve in this twentieth century, in the perpetuation, by so-called civilized nations, of as great crimes as the history of the world can show.

A good illustration of the development of the engineering profession is found in the history of the noted French corps of government engineers known as the Corps des Ponts et Chaussées. It was in the time of Charles V that professional engineers were first employed by the king to supervise public works, particularly roads, which were known as the king's highways. The corps experienced many vicissitudes, some rulers appreciating their work while others did not. In the time of Louis XIV, the engineers were pushed into the background, the king reserving his favor for the court architects. The architect, Mansard, was entrusted with the building of a bridge across the Allier at Moulins, but he was unacquainted with the principles of hydraulics, could not calculate the volume and force of the water, and did not know how to protect his bridge against floods, so that it collapsed a few years later. This disaster was favorable to the engineers, who pointed out that while it was the duty of architects to build fine palaces, engineers should be entrusted with the construction of public works where convenience and stability were of more importance than elegance. The Corps des Ponts et Chaussées was definitely and permanently organized between 1712 and 1716; and under Louis XV the noted École des Ponts et Chassées was constituted by royal decree dated February 14, 1747. It was placed under the direction of the engineer, Perronet, who besides other great works had built the beautiful Pont de la Concorde at Paris. At the beginning of the French Revolution, it was proposed to abolish the corps, but this move was defeated by Mirabeau, and instead the corps was reorganized by several decrees. The corps is now under the Department of Public Works. Five-sixths of its engineers come from the École des Ponts et Chaussées, while one-sixth come from foremen, who, after ten years' experience, are entitled to enter a competitive examination and if successful may be appointed engineers.

Perronet remained director of the school for 47 years after it was founded in 1747. He died February 27, 1794. The following year the École Polytechnique was founded, giving a general scientific training preparatory to the engineering school. The course in the engineering school extends over three years, offering free tuition in all courses, and state pupils are chosen exclusively from those leaving the École Polytechnique and receive a salary during their stay in Paris. During each vacation they are required to spend three and one-half months in practical work under the supervision of one of the engineers of the corps.

CHAPTER II

BRANCHES OF CIVIL ENGINEERING

In the previous chapter the development of the various branches of engineering was discussed, and the general field of *civil engineering* indicated. It should be remarked that by some the field of civil engineering is still considered to include all branches of engineering, with the exception of military engineering. In England, the "Institution of Civil Engineers" includes practitioners in all branches, and its discussions cover subjects in mechanical engineering, electrical engineering, naval architecture, etc., perhaps to an almost equal degree with civil engineering in its more restricted sense. Nevertheless, it seems proper at this stage of the development of the engineering profession, to restrict the field of civil engineering. In the present chapter the various branches constituting civil engineering in this restricted sense will be discussed, and their extent and the character of the problems which they offer will be pointed out. These fields, according to the enumeration already given, are the following:

(1) Surveying and Geodesy
(2) Railroad Engineering
(3) Highway Engineering
(4) Hydraulic Engineering

(5) Sanitary Engineering
(6) Structural Engineering
(7) Municipal Engineering

To these may be added the consideration of certain branches which involve the relations between engineering and various economical and sociological problems, which are now attracting considerable attention, such as valuation and city planning.

1. *Surveying and Geodesy*

Since engineering deals with works executed on the surface of the earth, which works must be designed, laid out, and constructed, it is clear that at its foundation must lie the ability to measure and delineate certain portions of the earth's surface; in other words, to make a survey and to represent the results upon a map.

Surveying is one of the first steps in any engineering project. If a building is to be built, an accurate survey must be made of the land upon which it is to be placed. The map showing the result of this survey, should indicate all necessary measurements and should show the relative elevation of different portions of the area, and if necessary, the character of the surface and of the objects upon it. The architect can then plan the location and elevation of his building, and the engineer can set the necessary stakes and lines preliminary to the beginning of the work of construction. Surveying involves, therefore, the measurement of areas supposed to be projected upon a flat surface, also the measurement of elevations. The notes of these measurements are plotted upon a map with the degree of detail which the conditions require.

A similar procedure must be followed if a bridge is to be built, in order that the abutments and piers may be located in precisely the desired places, and accurate dimensions obtained for their design and that of the superstructure. If the bridge is to cross a river, direct measurements of the length may not be possible, and measurements must be made upon one or both banks, from which, by mathematical computations, the necessary dimensions across the stream may be ascertained. In the course of construction, the surveyor must be at hand to see that the proper lines and grades are observed. If a pier is to be built in mid-stream, the location of the works must be indicated to those in charge of the floating equipment, by observers stationed upon the banks, who make the necessary measurements and observations.

Extreme accuracy is sometimes required in the work of the surveyor. If he is giving the lines or making the surveys for a building where land is very expensive, as for instance, in the business section of a great city, an error of a small fraction of an inch may be a serious matter, for if an owner proceeding to erect a building on Wall Street in New York should discover that an adjoining owner had built his building so that it encroached even by a fraction of an inch upon the adjoining lot, an adjustment of the matter might involve thousands of dollars. If the engineer is locating a bridge pier in mid-stream, extreme accuracy is equally important in order that when the pier is built, the steel superstructure which has been designed and built in the bridge shop, may rest upon it in exactly the proper position.

The work of the surveyor often involves extended travel and severe exposure. In the construction of a line of railroad, for instance, the first step is to make a survey in order to ascertain where the line should be placed. This decision is usually made by a locating engineer, who, equipped with the necessary instruments, travels on foot or on horseback, or by some other means of conveyance, over the country in which the line may be located, observing elevations, distances, and topographical configuration, and as a result of his decision, the surveyors lay out the line, indicating the center line by means of stakes, and when this line has been finally located in a position satisfactory to the engineer, it serves as a base for the work of construction. This will be referred to later under the head of railroad engineering, but it is here evident that where a line has to be located in mountainous and otherwise difficult country, the work of the surveyor may be arduous and difficult. It should be noted, however, that the term "surveyor" does not usually include an engineer who does work of this kind, who is rather termed a railroad engineer, although the operations which he performs are those of surveying. The point to be observed is that work of surveying is an essential preliminary to almost any engineering project, that it involves accurate and painstaking work in the open air, in which an error of measurement may be attended by serious consequences. The proper prosecution of this work, and its representation upon paper, requires a knowledge of mathematics, principally of the branches of geometry and trigonometry. It also requires resourcefulness on the part of the surveyor in order that difficulties which are encountered may be properly met. In laying down a straight line upon the ground, for instance, if a building is encountered, the surveyor must be able to pass around it and continue the straight line on the other side. If he is laying out a railroad or an irrigating flume through a ravine with precipitous sides, he must be able to make the necessary measurements and place the proper marks upon the ground. The surveyor must, therefore, be active, athletic, healthy, as well as resourceful and possessed of the requisite mathematical knowledge.

The work of the surveyor, properly speaking, is principally requisite in measuring or laying out parcels of land. The public lands of the United States are laid out in sections of definite area, bounded by lines running north and south and east and west. For the proper laying out of these sections, county surveyors are appointed by the government. In order to carry on their work properly, it is frequently necessary for them to be able to make such observations as will enable them to determine the true meridian and also the position of a given point on the earth's surface. They must, therefore, have some knowledge of astronomy, so that they may be able to make observations at night by the aid of the stars, and may run the lines in the true directions.

An important branch of surveying is mine surveying, which enables the surveyor, by dropping a plumb line through a shaft, to run lines along subterranean channels and drifts and to know just where these lines lie below the surface, so that he can locate another shaft on the surface, which may be carried down to meet the underground workings. Similar operations are necessary in the construction of tunnels for railroad lines and other purposes. A survey of the surface of the ground having first been made, it is decided that a tunnel shall be built between two points fixed in position on the map and on the ground. The surveyor must be able, starting at these points on the surface of the ground, to indicate the direction of the line for the tunnel with such accuracy, both as to line and grade, that it will be directed between the two desired points. Sometimes the tunnel is begun at both ends, and the construction carried on toward the center. If the survey is correct and the lines and grades properly given, the two drifts come together with great accuracy. Sometimes an intermediate shaft is located upon the line of the tunnel and excavated from the surface to the proper grade, and drifts carried from this shaft in one or both directions to meet the drifts from the ends. Inaccuracy in this work may have serious results, for if the two tunnels from the two entrances should not meet at the same elevation, or on the same line, but with a considerable lateral and vertical divergence, or either, then the discrepancy would have to be corrected by additional excavation, inasmuch as the size of the tunnel is made only large enough to afford the requisite clearance for the vehicles which are to pass through it. If the tunnel should be in soft material, built with so-called shields, and finished and lined as they progressed, the adjustment of any considerable discrepancy might be extremely difficult. Great accuracy is, therefore, necessary in work of this kind, and when it is remembered that the work underground must be based upon measurements on the surface, and that in some cases these surface measurements are indirect, as for instance, where a tunnel passes under a body of water, the seriousness and importance of accuracy is evident.

In the construction of the Hoosac Tunnel on the Fitchburg Railroad in Massachusetts under Hoosac Mountain a shaft was sunk from a point nearly midway between the two ends, and the tunnel was built in each direction from this shaft, as well as from the two ends. The total length of the tunnel is 15,743 feet, or very closely 3 miles. When the drifts met, the deviation at one meeting point was 5-16 of an inch and at the other 9-16 of an inch, a remarkable example of accurate underground surveying.

The East Boston Tunnel which passes under the Harbor of Boston, connecting the city proper with East Boston, is 5,176 feet long between the nearest stations on each side. It is not straight, but on the Boston side there is a curve 1,789 feet long with a radius of 2,000 feet. The tunnel was built with a so-called shield, which was pushed forward through the clay of which the bottom of the Harbor consists, and behind the shield, as it was pushed forward, the concrete which formed the lining of the tunnel was placed. When connections were made there was a deviation of 0.84 inch in grade and 4 inches in line, which was considered satisfactory.

Even in the early days remarkably accurate work was done. In the construction of the Erie Canal, some 100 years ago, one of the engineers, Judge James Geddes, made a survey between Rome, N. Y., and the east end of Oneida Lake, embracing nearly 100 miles of levelling, and the difference at the junction of the levels was said to be less than 1 1-2 inches.

The accuracy which can be attained by skilled surveyors, as evidenced by the above instances, is remarkable, particularly when it is remembered that their work is based upon measurements made on the surface of ground, which is often undulating, and in which such accuracy as may be obtained in a physical laboratory is, of course, out of the question. Fog and smoke, also, sometimes make accurate measurements difficult, as in the case of the East Boston Tunnel.

When the operations of the surveyor cover such an extended area that the curvature of the earth's surface must be taken into account, that is to say, the figure of the earth, the work is said to belong to the field of *geodesy*. All ordinary surveying operations cover such areas that they may be considered as projected upon a horizontal plane, but where very large areas have to be considered, the fact that the earth is a spheroid has to be taken into account. The field of geodesy involves some of the most complex and intricate operations and computations in the whole field of engineering, and constitutes in reality a distinct science. In the survey of a state, for instance, a base line has to be measured with the utmost accuracy by the use of appliances such as micrometers, etc., like those used in physical measurements in the laboratory. Such a physical phenomenon as the temperature has to be taken into account and corrected, and measurements must be repeated again and again in order to eliminate errors. This base line is located, if possible, on land which is nearly level, so that errors due to differences of elevation, may be, so far as possible, eliminated. From this base line angular measurements are made to distant points on mountain tops or on buildings, until the entire state is covered by a net-work of triangles. By means of the necessary computations, the state boundaries may be marked by monuments, and the sub-divisions, such as counties, may be also laid out. Precise methods of leveling and other refinements, together with mathematical computations of great complexity, are often necessary.

The United States Coast and Geodetic Survey has in its charge the carrying on of measurements of this kind, with the object of providing accurate maps of the coasts and of the various parts of the country. The United States Geological Survey also carries on much work of this kind, coöperating with the various states in making state surveys. Among other problems upon which the work of the Coast Survey throws some light, and which have been the subject of its investigations, is that of the precise shape or figure of the earth considered as a spheroidal body.

Geodesists have at various times, aided by astronomical observations, computed the length of a degree of latitude at different parts of the earth's surface. A comparison of the results of such measurements show that the length of a degree of latitude is not everywhere the same, and by studying the variations, as well as by other measurements, the shape or figure of the earth is found with considerable accuracy.

The work of the U. S. Coast Survey affords good examples of the accuracy attainable at reasonable cost. Greater accuracy would be possible, but the cost would not justify it. This illustrates how the economic element should enter into all engineering work. The policy of the Coast Survey is to attain such accuracy as is justified, and no greater. The following examples may be given, for which I am indebted to Professor John F. Hayford of Northwestern University, long connected with the Survey, and to Messrs. William Bowie and R. L. Faris, of the Survey.

In running a line of levels, determining the elevation of different points and coming back to the starting point, the line will generally not close, that is to say, the level of the starting point will not be found at the end to be what was assumed at starting. For precise work in running levels between two points, each short section of the line is run once in the forward direction and once in a backward direction. The mean of the two results is accepted if within the allowed tolerance.

In the loop San Diego-Brigham-San Francisco, the closing error, as given by the unadjusted levels, is 0.2612 meters (about 0.86 ft.). The correction which would close this circuit of 3,027 kilometers is 0.086 mm. per kilometer (about 0.0054 inch per mile). Similarly, the correction which would close the circuit of 2,474 km. Reno-Brigham-Las Vegas-Reno, is 0.03 mm. per km. Nearly all the precise levelling done by the Survey in recent years closes loops with an average of very little over 0.00052 ft. per mile (0.00624 in. per mile). In triangulation, the average closing error of a triangle for 66 sections of primary triangulation was 1.04 seconds. In measuring base lines, the probable error of a modern base is 1 part in 3,000,000.

The topographic surveys made by the states, in connection with the U. S. Geological Survey, which show contour lines, are of great value to engineers in connection with the location of roads and railways, and also in studies of projects for water supply and water power.

In connection with surveys, photography is playing a more and more important part, and aerial photographs are also being used. A complete map of a city may be made by taking aerial photographs and putting them together. This is a promising future development.

The work of the surveyor or geodesist often involves public matters of importance, as in laying out town, state, or national boundaries, as laid down in grants, statutes, or treaties. In 1789, Major Andrew Ellicott, one of the early American surveyors, surveyed the western boundary line of the State of New York, the main object being to ascertain whether or not the town of Erie, Pa. (then Presque Isle), was in New York. The line was found to pass some twenty miles east of Presque Isle, and the area in which that town was situated was afterward purchased by Pennsylvania from the United States. The same engineer, in 1790, surveyed a large tract of land which had been sold to one Robert Morris, adjoining a tract which had been illegally leased from the Indians and the lease of which had been declared void by the State of New York. There was a dispute as to the boundaries of this area, the boundary line, as run by the surveyor of the Lease Co., being west of the present city of Geneva. Ellicott found the true line to be as far east of Geneva as the previous survey had found it west of that place, and the difference made 84,000 acres in favor of Robert Morris in what is now a very valuable and beautiful portion of New York. In 1811 Ellicott ran the northern boundary of Georgia, and in 1817, by order of the government, he made astronomical observations near Montreal to aid in carrying into effect some of the articles of the Treaty of Ghent.

In recent years, American topographical engineers have been called upon to make surveys of territory in dispute between Costa Rica and Panama, and more recently to lay out the line as fixed by treaty.

2. *Railroad Engineering*

Of all branches of engineering, none are of more benefit to the human race than those which improve means of transportation. Macaulay in his History of England, long ago, made the following striking statement to this effect. He said:

> "The chief cause which made the fusion of the different elements of society (in 1685) so imperfect, was the extreme difficulty which our ancestors found in passing from place to place. Of all inventions, the alphabet and the printing press alone excepted, those inventions which abridge distance have done most for the civilization of our species. Every improvement in the means of locomotion benefits mankind morally and intellectually as well as materially, and not alone facilitates the interchange of the various productions of nature and art, but tends to remove national and provincial antipathies and to bind together all the branches of the great human family."

It is very important for the young man contemplating the choice of a profession to perceive clearly its larger opportunities for service to the human race. It is also important for all of us, old or young, to realize the blessings which lie at our hand rather than to complain that we do not possess others, or to criticize those who have been the means of furnishing us with those we have, because, like all human beings, they made some mistakes.

Prior to the railroad era, land transportation was entirely by horse-drawn vehicles over roads which were, in most cases, of miserable character. Macaulay gives a striking description of the condition of the English highways in the seventeenth century. He says:

> "Those highways appear to have been much worse than might have been expected from the degree of wealth and civilization which the nation had even then attained. On the best lines of communication, the roads were deep, the descents precipitous, and the way often such as it was hardly possibly to distinguish in the dusk from the unclosed heath and fen which lay on both sides. Ralph Thoresby, the antiquary, was in danger of losing his way on the Great North Road of Barnby Moor and Tucksford, and actually lost his way between Doncaster and York. . . . Often the mud lay deep on the right and on the left and only a narrow track of firm ground rose above the quagmire. . . . It happened almost every day that coaches stuck fast until a team of cattle could be procured from some neighboring farm to tug them out of the slough. But in bad seasons the traveler had to encounter inconveniences still more serious. Thoresby, who was in the habit of traveling between Leeds and the capital, has recorded in his diary such a series of perils and disasters as might suffice for a journey to the frozen ocean or to the Desert of Sahara. . . . The great road through Wales to Holyhead was in such a state that in 1685 a viceroy going to Ireland, was five hours in traveling fourteen miles from St. Asaph to Conway. Between Conway and Beaumaris he was forced to walk a great part of the way and his lady was carried in a litter. In general, carriages were taken to pieces at Conway and borne on the shoulders of stout Welsh peasants to the Menai Straits. In some parts of Kent and Sussex none but the strongest horses could in winter get through the bog in which at every step they sank deep. The markets were often inaccessible during several months. It is said that

> the fruits of the earth were sometimes suffered to rot in one place, while in another place, distant only a few miles, the supply fell far short of the demand. . . .
>
> "When Prince George of Denmark visited the stately mansion of Pelworth in wet weather, he was six hours in going nine miles, and it was necessary that a body of sturdy hinds should be on each side of his coach in order to prop it. Of the carriages which conveyed his retinue, several were upset and injured."

We do not now realize the difficulties of transportation in this country a generation ago or a hundred years ago. About 1770 President Quincy, of Harvard College, described a stage journey between Boston and New York;—it required a week of hard traveling. In 1775, when Washington came to take command of the American Army, he was twelve days in coming from Philadelphia to Cambridge.

The stages in those days left very early in the morning, usually at 5 o'clock, but sometimes at 4, and sometimes even at 2. In 1826, Josiah Quincy traveled from Boston to New York in 4 days, and from New York to Washington in 4 more. At this period there was a law in New England prohibiting traveling on Sunday, except from necessity or charity, and this law was not repealed until 1887. There is an interesting story with regard to the enforcement of this law in the town of Andover, Mass.

> "The good people of that town being very much disturbed by wicked violations of the law, determined to have it strictly enforced, and appointed a worthy deacon to see that the officers performed their duties. He accordingly denied himself the privilege of going to church, and sta-

tioned himself with the officers at a toll gate just outside the town. A gentleman traveling in a carriage was stopped and told that he could go no farther. With great courtesy he said: 'Gentlemen, I am fully aware of the provisions of law, and, of course, it is proper that you should enforce them, but you must remember that those people are excepted who travel from necessity or charity. Now, gentlemen, the fact is that my mother is lying dead in Boston and I ask that I may be permitted to pass.' After consultation they allowed him to pass. When he had reached a safe distance, he stopped and called back, 'Don't forget to tell the good people of Andover that you permitted me to pass because my mother is lying dead in Boston, and you may add, also, if you please, that she has been lying dead there for some twenty years.' "

When General Grant left his home in Georgetown, Ohio, in 1839, to go to West Point, there were no telegraphs, no railroads west of the Allegheny Mountains, and but few east. He went by boat on the Ohio to Pittsburgh in three days, although he suffered no vexatious delays, which were common, sometimes lasting two or three days. From Pittsburgh he went to Harrisburg by canal, the canal boats being carried over the mountains on inclined planes. At Harrisburg he took the railroad and proceeded at a speed averaging 12 miles an hour, which to him "Seemed like annihilating space." The roads of those times, at any rate in New England, were almost without exception absolutely straight, veering neither to the right nor to the left. When a hill was in the way, they went over it. The charters of the turnpike corporations, in defining the route, generally required that the road should be built nearly straight, or as straight as possible. It was not realized that it is sometimes as far, and almost always a great deal harder, to go over a hill than around its base. On the Salem Turnpike a very small but peculiarly deep pond was encountered. The builders would not go around it, but built a floating bridge over it, which is still in use.*

The facilities for traveling were not as great as in the time of the ancient Romans. Gibbon tells us of the excellence of the Roman roads and of a magistrate, who, in the time of Theodosius, traveled from Antioch to Constantinople, a distance of 665 English miles, in 6 days. Gibbon says, "Houses were everywhere erected at a distance of only 5 or 6 miles, and each of them was constantly provided with 40 horses, and by the help of these relays it was easy to travel 100 miles a day along the Roman roads."

Yet in 1826, as Mr. Quincy tells us, when the journey from Boston to New York required 4 days, travelers "congratulated themselves upon living in the days of rapid communication" and "looked with commiseration upon the condition of our fathers, who were wont to consume a whole week in traveling between those cities."

During the era just preceeding the advent of the railway, many canals were built in the United States. In 1792, a charter was granted for a canal from the

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* A good deal of very interesting information regarding these matters is contained in a paper by Hon. George G. Crocker, published in 1900, entitled "From the Stage Coach to the Railroad Train and the Street Car." This paper has been largely used in the preparation of this article. It will well repay study.

Connecticut River to Boston, but it was not built. In the following year, a charter was granted for a canal from the Merrimac to near Boston. This Middlesex Canal was opened in 1803 and continued in use for about 50 years. It was 27 miles long, 30 feet wide, and 4 feet deep, and boats traveled at the rate of about 2 miles per hour. The opening of the Erie Canal in 1825 revived the agitation in favor of canals, and the legislature of Massachusetts appointed a committee to consider the feasibility of a canal, not simply between Boston and the Connecticut River, but between Boston and the Hudson River. The Committee reported that such a canal was feasible and advisable. The estimated cost was $6,000,000. The committee recommended that the funds should be raised by a lottery run by the state.

In 1826, Gridley Bryant obtained a charter from the Legislature of Massachusetts to build a railroad from the granite quarries in Quincy to the Neponset River, for the purpose of carrying the stone to be used in the construction of Bunker Hill Monument. This road was built and put in operation in October, 1826. It was built with stone ties and was operated by horses. It was not the first railroad in America, some small ones having been built previously by laying scrap rails on wooden stringers, all for horse operation. In 1827-28 some short lines were built for carrying coal in Pennsylvania. In 1829, Horatio Allen made a report to the Directors of the South Carolina Railroad recommending operation by locomotive steam power.

This was, consequently, the first railroad which was authorized to be built expressly for locomotive steam power. The directors of the Liverpool and Manchester Railroad in England had not determined at that time what power should be used.

The charter of the Baltimore & Ohio Railroad was granted in 1828 and a portion of the road was opened in 1830, operated by horses. In 1829 a commission reported to the Massachusetts Legislature recommending the construction of a railroad to the Hudson River, the tracks to be laid on two parallel stone walls surmounted by a rail of granite with a bar of iron on the top to form the tracks. This commission recommended operation by horses and suggested that a platform on wheels be provided for long down-grades, on which the horse himself might ride down hill. The same expedient has been actually used on one or two short roads in the United States within 20 years, in which a tram car was provided with a rear platform on which the horse could ride down hill.

Some of these early roads contemplated the operation of railroads in a manner similar to that of turnpikes, the idea being that any person could drive his cart or carriage on this road, only horse-power being thought of.

Mr. Crocker gives an interesting brief account of the development of the steam locomotive, which is as good a brief account as the writer is acquainted with.

The modern railway is thus less than a century old. The earliest English railways, namely, the tramways on the Tyne and Tees, were built to carry coal. The first passenger line was that between Stockton and Darlington, a distance of 12 miles, which was opened for traffic in 1825. When this line was first considered passengers were not thought of, and it was only while the works were in progress that the starting of a passenger coach was seriously contemplated. A coach called "The Experiment" was built and drawn by one horse. The first act providing for the construction of this line required that it should be free to all parties who chose to use it at prescribed rates, and that anyone could put horses and wagons on the railway and carry for himself. The first considerable passenger line was that between Liverpool and Manchester, which was opened in 1830. Before its opening there was much dispute as to whether it should be operated by locomotives or by stationary engines. Finally the directors decided in favor of locomotives and offered a prize of £500 for a locomotive which should best fulfill certain requirements, the chief of which were that the engine must consume its own smoke, attain a speed of 10 miles an hour with a boiler pressure of not over 50 pounds, and must haul a load fixed in proportion to its weight. A memorable competition was held at Rainhill in October, 1829, and was won by Stephenson's "Rocket," which hauled a coach containing 30 passengers at the rate of 26 to 30 miles an hour. The "Rocket" weighed, with coal and water, 4½ tons.

The first locomotive built in the United States and operated on a track without a rack rail was the "Tom

Thumb," which was run upon the Baltimore and Ohio Railroad in 1829. On its first trip it had a race with a car drawn by a horse, which was won by the horse.

From these early days of the railroad, within the short space of less than a century, the modern railroad has been developed by the genius of engineers, until to-day, as everybody knows, every civilized country is traversed by these iron roads, on which locomotives operate, that weigh, with their tenders, over 200 tons, and run at speeds of over 60 miles per hour. The construction and operation of these roads is a field of the civil engineer.

Although most civilized countries are now adequately provided with railroads, there are still many more to be built in undeveloped countries, and even the existing roads must be enlarged and provided with increased facilities in the way of additional tracks, terminals, equipment, signals, etc. South America has but few miles of railroad in proportion to its area, and it is not long since a line over the Andes connecting Chile and the Argentine Republic was completed. Even in our neighboring country of Canada two new transcontinental lines have been built within about 10 years, one of them affording a continuous line of rails across the continent with a grade of not over 0.4 per cent from Winnipeg to the Pacific Coast. The great Canadian Pacific line from Montreal to Vancouver, a distance of 2,906 miles, was begun in 1874 and formally opened in 1886. This line, as most people know, was at first built with heavy grades, but within recent years, by the construction of tunnels, some of these built in loops so that there is a corkscrew within a mountain, this line has reduced its grades to reasonable modern limits. On some of our mountain roads these loops, twists and turns are very common because of the necessity of rising a considerable vertical distance in a very short horizontal distance, and sometimes four levels of railway can be seen from a single point.

Not only does the engineer build railroads over mountain ranges by means of tunnels, spirals, and loops, but he carries the iron horse to the very tops of mountain peaks, by means of the so-called rack rail. A continuous rack is laid between the two rails, and a pinion on the locomotive engages with this rack, so that the locomotive is able to haul a light load up a very steep incline. Everybody is familiar with the rack railroad leading to the top of Pike's Peak, and travelers in Europe are familiar with similar roads up the Rigi and Mount Pilatus, and other Swiss mountains. The engineer goes further. He carries passengers in suspended cars carried by wheels overhead running on a cable or a track, not only over the city streets, as in Elberfeld in Germany, but to the lower summits in Switzerland.

With the expansion of transportation, and especially with the need of rapid transportation in cities, elevated and underground roads have been built, as in Boston, New York, Chicago, Berlin, London, Paris, and other cities. In New York City the subway system is very extensive, and near the Grand Central Station there are four levels of transportation, one above the other. Tunnels are built to carry high speed trains under the Thames at London, the Mersey at Liverpool, the Hudson at New York, the St. Clair at Detroit, and with the advent of electric power, there is no doubt that at some time there will be a tunnel under the English Channel. The St. Gothard Tunnel in Switzerland is 9-1/3 miles long; the Mont Cenis Tunnel is 8-1/4 miles long, and the latest tunnel, the Simplon, is 12-1/4 miles long. There are 52 tunnels on the line between Florence and Bologna, and more than that on some of the mountain roads in the United States.

When the Union Pacific Railroad was built and arrived at Salt Lake, it found that great body of water lying directly across its path. The possibility of carrying the line across the lake was considered but given up, and the road was diverted to the north around the shores over a steep and crooked route. When Mr. Edward H. Harriman obtained control of the road he approved a project to build the so-called Lucin Cut-off, which runs straight from Ogden over the lake on a trestle nearly 12 miles long and on 20 miles of fill. This cut-off saves 43 miles of distance and eliminates much curvature and many steep grades, but it was not constructed without many difficulties and much discouragement, over all of which the engineer triumphed, until in 1903 the new line was opened.

Notwithstanding the substantial completion of our lines of railroad, they still require the expenditure of almost as much money on new construction, for improvements and enlargements, as at any time in the past. The civil engineer is the man who designs and carries through this work. He must have the vision to see possibilities; he must have the financial acumen to determine whether they are worth while; he must have the power of convincing others, which will enable him to secure the approval of his plans; he must have the executive ability and the power of controlling other men, to enable him to carry them to a successful completion.

One of the greatest wonders in connection with railroads is the safety with which they are operated. We occasionally hear of a railroad wreck in which many people are killed, and we are thrilled with horror! We do not stop to think or to learn that more people are killed by street cars, by automobiles, or even by lightning, than are killed by railroads. The safety of their operation is remarkable when fairly considered. By means of automatic signals, by means of brakes which can stop a train moving at 60 miles per hour within a distance of 1,060 feet, and by safety appliances of many kinds, the danger of railroad travel has been so reduced that it is almost negligible, and yet there is still abundant opportunity for providing greater safety. Many lines are inadequately provided with signals and other safety appliances. The field and the prospects for the railroad engineer are continually growing. Moreover, the civil engineer, who engages in railroad work, may now look forward, if he is deserving, of being called upon, not only to construct, but to direct and manage the operations of our railroads. Not a few railroad presidents have come up from the corps of engineers, and if the civil engineer, instead of confining himself to narrow technical details, as he too often does, will study the questions of railroad management and financial policy, he will find abundant opportunity for the exercise of talents of the highest order.

3. *Highway Engineering*

The construction of roads is one of the oldest branches of engineering. The Romans built an elaborate system of roads, having a roadbed which is said to have been in some cases 4 feet thick, with large stones at the bottom. This is much thicker than is even now necessary. The Romans also built stone arches and aqueducts that have endured until the present day.

Gibbon tells us that all the cities were connected with each other, and with the capital, by public highways; the great chain of communication from the wall of Antoninus in Britain, to Rome, and thence to Jerusalem, having a length of 3,740 English miles.

In the middle ages the roads were neglected, and even up to the middle of the 18th century the roads in every country of Europe were in a frightful condition. About that time, Tresaguet, in France, began the construction of the modern system of roads which have become famous; and McAdam and Telford, in England, gave their attention to the subject. Tresaguet used a foundation of large stones, with a surface of smaller stones. McAdam placed his surface of broken stone directly upon the prepared ground, without stone foundation, a surface known by his name, modified to "macadam." Telford modified McAdam's construction by adding a foundation similar to that which Tresaguet had used earlier. Since then the construction of roads has steadily increased, and it is recognized that the excellence of its roads is a good measure of the civilization of a country. The growth of cities, too, has led to the introduction of many forms of street pavement.

The business of the highway engineer is to know how to locate, construct and maintain roads and pavements. Many roads have been badly located, running in too nearly straight lines, up hill and down, without sufficient reference to grade. It was not realized that a road over a hill may be longer, as well as much harder than one around its base. Since a grade limits the load that can be hauled, many roads have had to be relocated, or the grades have been made easier by cutting the summits and filling the hollows.

The proper construction and drainage of a road is important, and the engineer must know how to make use of available materials in a way to secure economy of original cost and of maintenance. He must know the physical and chemical qualities of the various materials, and how to test them. The kinds of materials and of roads are numerous. First there is the ordinary dirt or gravel road, which, if properly constructed and maintained, is about as pleasant as any to ride over, except for dust and sometimes mud; then there is the macadam road with a surface of broken stone, properly screened and rolled, and with a surface binder; then there is the same with a Telford foundation of heavy stones, which is better suited for severe traffic; then there is the concrete surface which has recently come into use; and finally there are the various bituminous materials now used for roads. The use of these bituminous materials has come within recent years, and has practically opened an entire new field to the highway engineer, requiring a knowledge of the chemical properties of these materials in order to secure proper results. For city streets there are numerous materials and forms of construction, such as wood blocks, stone blocks, brick, macadam, asphalt, bituminous concrete, and cement concrete, each applicable under certain conditions and varying in cost and wearing power.

Since the advent of the automobile the interest in good roads has received a great impetus, and great sums are being expended by the states and by the national government for road construction. The first state to create a state Highway Commission was Massachusetts, which established such a commission in 1893, though other states had previously appropriated money for road construction. Many states now have such Commissions, which coöperate with the U. S. Government in the expenditure of money for road construction. Massachusetts has expended for road construction approximately the following sums in the years specified, which give an idea of the increasing importance of this subject:

In 1895	construction	$400,000;		
1900	"	500,000;		
1905	"	450,000;	maintenance	$60,000
1910	"	500,000;	"	503,627
1915	"	1,000,000;	"	1,004,006
1920	"	1,000,000;	"	2,916,650

"In 20 years the State has expended for the construction of state highways and local roads $23,000,000, and for maintenance $15,000,000, a total of $38,000,000. The cost of state highways has increased from $6,800 per mile in 1895 to an average cost for the modern road in 1921 of approximately $45,000 per mile."

The Bureau of Public Roads of the Department of Agriculture gives the following table of funds reported as available for highway construction in 1921, which will give some idea of the magnitude of the road construction program:

State	Funds Available for Road and Bridge Expenditures, 1921
Alabama	$9,000,000
Arizona	8,000,000
Arkansas	12,000,000
California	26,000,000
Colorado	7,000,000
Connecticut	8,000,000
Delaware	3,500,000
Florida	7,725,000
Georgia	10,000,000
Idaho	4,500,000
Illinois	20,000,000
Indiana	9,500,000

State	Funds Available for Road and Bridge Expenditures, 1921
Iowa	$37,000,000
Kansas	20,000,000
Kentucky	8,000,000
Louisiana	6,000,000
Maine	7,500,000
Maryland	4,800,000
Massachusetts	8,000,000
Michigan	20,000,000
Minnesota	20,000,000
Mississippi	11,000,000
Missouri	15,000,000
Montana	8,500,000
Nebraska	6,000,000
Nevada	3,500,000
New Hampshire	2,500,000
New Jersey	16,000,000
New Mexico	4,000,000
New York	55,000,000
North Carolina	6,500,000
North Dakota	7,000,000
Ohio	35,000,000
Oklahoma	8,000,000
Oregon	10,000,000
Pennsylvania	30,000,000
Rhode Island	1,700,000
South Carolina	6,000,000
South Dakota	7,000,000
Tennessee	10,275,000
Texas	60,000,000
Utah	6,000,000
Vermont	2,000,000
Virginia	10,000,000
Washington	14,000,000
West Virginia	8,000,000
Wisconsin	19,500,000
Wyoming	3,000,000
Total	$622,000,000

The approximate total cash expenditures for roads and bridges, for all the states, is stated as follows: *

In 1904	$59,527,170
1914	240,263,784
1917	279,915,332
1918	286,101,198
1919	389,455,932

Many states have now hundreds or thousands of miles of magnificent roads of concrete, bituminous material, or macadam, over which not only a vast pleasure traffic passes, but a large tonnage in trucks, some of these trucks weighing as much as 20 tons loaded.

These figures will serve to show the growing importance of road construction, and the magnitude of the field it opens to the civil engineer.

It is sometimes claimed that the motor truck should replace the freight car for freight transportation for short hauls, and that it can economically do so. The writer considers this a great mistake. The cost of transportation by truck is much greater per mile than the cost by rail, especially if the cost of road construction and maintenance is considered, as, of course, it should be. It is easy to prove any statement if suitable elements of the problem are omitted from consideration. The interest and amortization charged on the cost of roads, and the cost of maintenance, should, of course, be apportioned to the traffic carried, in order to estimate properly the cost of transportation. These charges are high, and there is no doubt that

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* "Public Roads," September, 1920, p. 12.

traffic by heavy truck is largely responsible for the wear of a road.

Transportation of freight by rail, unless freight is loaded directly from its source at one end into a freight car on a siding, and similarly unloaded at the other end, involves trucking at each end, the cost of which must be considered. A manufacturing establishment may, therefore, distribute its products more economically by truck than by rail within a certain limited distance. The question is, what is the cost from source to destination? In estimating this cost, the cost of roads and their maintenance should not be omitted, or the estimate may be grossly in error. This error is sometimes made in comparing the cost of transportation by canal with that by rail, and the cost by canal is sometimes taken as the mere cost of haulage, the interest on the cost of construction and the maintenance charges being entirely omitted, because they are paid by the state or the government. The railroad company has to pay its overhead charges and the interest on its fixed obligations, so that such a comparison is, of course, of no value.

The heavy motor truck has its proper functions, but with the popular enthusiasm for automobiles, we are apt to go too far, and to overestimate their importance and economy. The railroad is and will always remain, under normal and proper conditions, the most modern and economical method of transporting freight. While this does not detract from the importance of good roads, there does seem some danger that the road-building program will be over-extended, as was the case with canal building a hundred years ago, as will be noticed, and that some states will find themselves unduly and unhappily overburdened with financial obligations for such construction. Balance and a clear vision are necessary in this, as in all things. The sum of $622,000,000 for road construction, as given in the table on page 55, is an enormous sum, and it may well be that it is in part extravagant and unreasonable, though the writer cannot prove that it is. Especially at the present time, when the world is trying to recover from the greatest cataclysm in history, it is necessary to practice economy—individual, municipal, and state—to keep our feet on the ground, and to indulge in no schemes of public expenditure that cannot be proved to be self-supporting or fully justified by benefits to be received.

4. *Hydraulic Engineering*

This branch of the profession, as its name implies, deals with problems involving the use and control of water. Certain branches, such as water supply and sewerage, which deal largely with questions of the public health, and those involving chemistry and bacteriology in their relations to disease, are properly included in the field of sanitary engineering, and are described under that head. What is left of hydraulic engineering, however, is still a very extensive field, covering:

(a) The development of water power.
(b) The regulation of rivers, including the control and prevention of floods.
(c) Canals.
(d) Coast and harbor works.
(e) Irrigation engineering.
(f) Reclamation of marsh lands.

(a) The development of water power is one of the most important branches of hydraulic engineering, and one of the most important for the progress of civilization. This is an age of power, in which almost every industry is dependent upon the use of power. The only methods of generating power are by the combustion of fuel and the utilization of water power. Every pound of fuel which is burned is lost forever, and can never be replaced; nevertheless, the consumption of fuel, including coal and oil, has been increasing at a tremendous rate, and if this rate of increase continues the available supplies, so far as are now known, will certainly be exhausted at some future time, which is perhaps not very far off, historically speaking. What the world will do when that time comes is problematical; perhaps other supplies will be discovered, or other methods of generating power, as, for instance, from the sun or by some chemical means. The patent fact, however, is that fuels are exhaustible and cannot be replaced.

On the other hand, every pound of water that falls over a rapid or waterfall generates a power which, if *not* used, is lost forever; but other pounds of water will continue to fall over that rapid to supply the place of that which has been lost. It may therefore be said that every pound of fuel which is burned is lost forever, while every pound of falling water *not* utilized is lost forever, though other pounds of water take its place. The desirability of developing water power and conserving our fuel supply is, therefore, evident. Such development should be encouraged in every possible way. Unfortunately, the fixed investment in a water power plant is larger than that of the steam plant of the same capacity, so that the fixed charges are greater, although the operating expenses are less in the case of water power. The large fixed charges, and the fact that a water power plant can only be used for one purpose, have been the causes of the lack of success of some water power developments. Then, too, the attitude of some states and of the United States Government, instead of encouraging the development of water power, has distinctly discouraged it by placing upon it various restrictions, burdens and taxes. With the increasing cost of fuel, however, and a more enlightened public sentiment, it is probable that in the future the development of water power will be encouraged. It is now possible to transmit power by electricity for a distance of some 500 miles from its source. Therefore, although a water power may be located in an inaccessible mountain district, it may be transmitted and utilized a long distance away, or it may be used for electrifying railroads passing through the mountains.

The development of water power requires a thorough acquaintance with the laws of hydrology, that is to say, of rain fall, the flow of streams, and the effect of reservoirs; it requires a great deal of structural work in connection with the construction of dams, canals, flumes or aqueducts; and it also requires the work of the electrical and mechanical engineer in the planning of the machinery for power development and the transmission lines. Sometimes, by taking advantage of a bend in a river, the building of a short canal will permit the development of a very large power. In France and other foreign countries the development of water power is receiving much attention, and a project has been prepared for making the River Rhone navigable from its mouth to Lake Geneva, and for developing, incidentally, a very large amount of water power, which can be transmitted to the manufacturing cities of France or used for electrifying the railroads. This branch of civil engineering is most interesting and will offer increasing opportunities.

(b) The next three branches which have been named have largely to do with transportation by water. Rivers may be made navigable by the construction of locks and dams; canals may be built for inland navigation, as well as for sea-going vessels, as in the case of the Suez Canal and the Panama Canal; and coast and harbor works are needed for the protection of shores and for facilitating commerce.

The various uses of a river are in a measure interdependent. The development of a water power on a river may be connected with rendering it navigable, with regulating its flow, with the use of the water for irrigation, and for the water supply of cities. The proper use for one of these purposes may be consistent or inconsistent with its proper use for another. The proper regulation of a stream for the development of power requires that the reservoirs, if there are any, should be drawn upon in such a way as to permit an equable flow. The best use for irrigation may require a somewhat different utilization of the reservoirs. All these various uses of water must be understood by the hydraulic engineer, and he must be able to study a large project or carry on a given work in such a way as to permit of the best development.

The prevention and control of floods is an important subject for the hydraulic engineer. Some rivers have an equable flow and rise but little in times of flood; others, like the Ohio River, have a difference of level of 60 or 70 feet between high water and low water. In 1913 large areas in the states of Ohio and Indiana were visited by an extraordinary flood which destroyed great amounts of property. Since that time a Flood Commission has been created to study the problem and devise means for regulating the flow of the streams and controlling the floods so that there will be as little danger from them as possible. Movable dams are used on some streams, which may be raised or lowered as required.

(c) Canals are an important branch of engineering for the hydraulic engineer. The most obvious opportunity for a canal is, of course, to cut across a narrow isthmus separating two seas on which vessels of deep draft navigate. Instances of this are the Suez Canal and the Panama Canal; similar instances are the Welland Canal between Lake Ontario and Lake Erie, and the Sault Sainte Marie Canal between Lake Superior and Lake Michigan; all of which connect bodies of water of considerable depth. The construction of such a canal may save several thousands of miles of deep water transportation.

The Pharaohs dug a canal from the northern extremity of the Red Sea or the Gulf of Suez westward to the nearest branch of the Nile in the eastern Delta where the river divides into a number of mouths, so that ships from the Mediterranean could sail up the easternmost mouth of the Nile, enter the canal, pass through it and reach the Red Sea. Thus the Suez Canal was anticipated some 4,000 years ago by the ancient Egyptians. As everybody knows, the present canal was carried through largely by the efforts of the French financier, De Lesseps, not on the location above described, but straight across from the northern extremity of the Red Sea to the Mediterranean. This canal shortened the distance from London or Liverpool to India by several thousand miles, and was a monument to the engineers who carried it out. It is interesting to note, however, that Robert Stephenson, perhaps the most noted engineer of the last century, opposed its construction, maintaining that it was impracticable. It is obvious that even the greatest engineers sometimes make mistakes.

The Panama Canal was first projected by French engineers, but after several attempts, was given up by them and completed by the United States Government. Like the Suez Canal, it saves thousands of miles of ocean transportation, between ports of the North Atlantic and ports in the Pacific Ocean.

Canals for inland navigation have at times been very extensively constructed, and have required the services of many engineers. Before the era of the railroad the only means of transportation were by common road and by water. Transportation by canal was cheaper than by road, and in the early part of the last century many canals were constructed both in England and in this country. Some of the states of the Union appropriated large sums for canal construction, believing that they were laying the foundations for future greatness. Most of these canals, however, have now been abandoned. The only canal for internal navigation—aside from those connecting deep waters—which has survived in the United States is the Erie Canal. The first Erie Canal was 28 feet wide at the bottom, 40 feet wide on top, and 4 feet deep, with locks 90 feet by 12 feet. At the time it was built it was the longest canal in the world, built in the shortest time, with the least experience, for the least money, and to the greatest public benefit. By affording a means of transportation between the Hudson River and the Great Lakes it may even be said that some of the states beyond the Mississippi River almost owed their existence to it. At one time, in the amount of its transportation and tonnage, it far exceeded the whole foreign commerce of the United States.

The construction of this canal was followed by the construction of others, and by surveys for the construction of others still. Pennsylvania had a system of canals which, in connection with inclined planes, enabled canal boats to pass over the Allegheny Mountains. The boats were run upon a truck or car which, by means of cables, was hauled up a comparatively steep incline to the summit and allowed to go down a similar incline on the other side. The Chesapeake & Ohio Canal was built to connect the Atlantic seaboard with the Ohio River. Virginia had canals, and so did Ohio and Indiana; but all of these are now abandoned. The advent of the railroad provided a means of transportation so much easier and quicker, and also less expensive, that the canals proved useless, and the money expended for them was wasted. Several states experienced serious financial difficulties on account of the appropriation of large sums of money for canal building.

As already stated, the only canal which survived was the Erie Canal, but this proved inadequate and the traffic upon it greatly diminished and at last became practically nil. The state of New York, however, undertook to enlarge it, and has constructed the so-called Barge Canal in its place, extending from the Hudson River to Lake Erie, with a depth of 12 feet. Whether this investment will prove profitable is at least doubtful.

(d) The construction of coast and harbor works is a growing field for the hydraulic engineer. A coast city must have docks, piers, dry-docks; its channel must be kept dredged; light houses must be built; loading and unloading devices must be provided at the piers; and the interchange of freight must be facilitated, if commerce is to increase. The study of port development has engaged the attention of a number of commissions and the services of many engineers.

In improving harbor entrances, not only dredging but sometimes submarine mining and blasting are necessary. At Hell Gate, N. Y., in making a suitable channel between Long Island Sound and the East River, a network of galleries was excavated under the reef, having a total length of nearly a mile and a half; the roof, from 6 to 20 feet thick, resting on pillars of rock. About 4,460 holes were drilled in the roof and filled with explosive, and in 1876 all these were exploded simultaneously, blowing off the entire roof. The Middle Reef was afterward blown off (in 1885) in the same way, by means of over 4 miles of galleries and 12,560 holes.

The improvement of the mouths of large rivers often gives rise to great engineering undertakings. A large river may bring down great quantities of sediment which are deposited as a bar across its mouth. In some cases the river may have several mouths as, for instance, the Mississippi, the Danube, the Nile, the Ganges and others. If the river is navigable, it is necessary to keep one mouth open with a sufficient depth of water. This may be done by dredging or by making the river do its own dredging by confining the channel between jetties and so making it scour out a channel for itself. Probably everyone has heard of the improvement of the Southwest Pass of the Mississippi River which was undertaken by Captain James B. Eads almost half a century ago. In this case jetties were built, which have been successful in maintaining the required navigable depth, so that large vessels may proceed up the river to New Orleans and other ports. English or American engineers have frequently been called up by foreign countries to advise and draw plans for improvements of this kind, as in the case of the mouths of the Danube and the Rio de la Plata.

Harbors are frequently protected by breakwaters or jetties within or between which vessels may lie or discharge at wharves or in basins. The construction of harbors is a very important field of civil engineering and involves a study of the ocean currents and their effects. Sea-walls and jetties are exposed to the force of the waves, which, in the case of heavy storm, may be very great. The construction of lighthouses also involves a consideration of these forces and of many difficult and trying engineering problems. The construction of such lighthouses as Eddystone Lighthouse in England is generally considered one of the triumphs of engineering.

The difficulty of building a lighthouse on a limited ledge of rock, frequently submerged, and only approachable in calm weather, may perhaps be appreciated even by the layman. The Eddystone Lighthouse, in the English Channel, is 9 miles from the nearest coast of Cornwall, and had been the scene of frequent wrecks. Four lighthouses have been successively built there. The first was of wood, and was completed in 1700, and washed away in 1703. The second was also of wood, completed in 1709, and destroyed by fire in 1755. The great engineer, Smeaton, built the third, of stone, completed in 1759, and although the waves sometimes dashed over the lantern, it remained intact: but the sea began to undermine the rock on which it stood, and it was decided to take it down after erecting another on an adjacent rock. The new one was of stone, completed in 1881. The range of the light from this lighthouse is 17½ miles.

(e) Irrigation engineering is so extensive as to constitute almost a field in itself. In the western states, where the rainfall is insufficient for growing crops, there are large areas of fertile land which only require the application of water to make them blossom like the rose. Therefore, irrigation projects were early developed for utilizing the streams by turning the water upon the land. Similar works have been necessary in Italy, India, Egypt, and elsewhere. In India there are thousands of reservoirs, and large areas are irrigated, for, while the rain fall in northern India is greater than anywhere else on the globe, in other sections of that country it falls so low in some seasons that irrigation must be depended upon to support the people.

(f) The reclamation of marsh lands is an increasing field for the hydraulic engineer. Large rivers, like the Mississippi, when in flood, overflow great areas, which, when the flood subsides, are only partly dry and cannot be cultivated unless they are reclaimed by being enclosed with embankments which will keep the river from overflowing them and protect the crops. Everybody knows that a large part of Holland has been reclaimed from the sea. It was originally under water or partly so, but the construction of dikes and proper protective works have brought under cultivation areas now inhabited by many thousands of industrious people.

Enough has been said to show conclusively that the field of hydraulic engineering is a most important and extensive one; that it is a clean and interesting branch of the profession; that it requires great ability and a thorough knowledge of hydraulics, structures, materials, and hydrology; and that as long as civilization advances and commerce increases, as long as power is used, and as long as our rivers flow down hill, there will be always abundant opportunities for the hydraulic engineer to construct works for the benefit and convenience of man.

5. *Sanitary Engineering*

It is impossible to overestimate the importance of this branch of engineering as a contributing factor to modern civilization. It deals with the following subjects:

(a) Water Supply, of the individual and of communities.
(b) Sewerage Systems, for the individual and for communities.
(c) The Purification of Water and Sewage (including Trade Wastes) and the Disposal of the latter.
(d) Street Cleaning and the Disposal of Garbage.
(e) Heating and Ventilating.
(f) Swamp Drainage.

The importance of providing supplies of pure drinking water for communities, and of disposing of their sewage and garbage, are self-evident; and with the increasing size of cities these problems increase in number and in difficulty. At the beginning of the last century only about 3 per cent. of the population of the United States lived in cities; in 1910, 45.8 per cent. of our population was urban (i.e., living in cities and towns of over 2,500 population), and in 1920, 51.4 per cent; our largest city, New York, has a population of 5,621,151. The number of cities having a population exceeding 100,000 is 68, and the number having a population exceeding 25,000 is 288. There are 3 cities having over a million inhabitants, 12 having over 500,000, and a number of instances where several large cities are close together, forming a metropolitan district of enormous size. The population of the so-called Metropolitan District of Boston was 1,070,256 in 1910, and 1,252,903 in 1920; and it is said that 6 per cent. of the population of the country lives within a radius of 25 miles of New York, and 12.5 per cent within a radius of 100 miles, this limit including Philadelphia.

The problem of supplying these immense congregations of people with the necessaries of life—with water, milk, ice, provisions, and transportation—is almost appalling. In regard to some of these it is a question of transportation, by rail or by highway. In regard to water it is a question of finding an adequate and sufficiently pure source of supply, bringing it to the city by gravity or by pumping, and distributing it by pipes under the streets.

Equally great are the problems of disposing of the wastes and garbage of these great cities, in such a way that they will not be a menace to the health or comfort of other communities.

While the growth of urban population may be deprecated, and even though it may be proved that health and civilization will be promoted by a life in the country, the phenomenon is one of the most striking sociological facts of the past century, and it shows no tendency to change its trend, notwithstanding the cry of "back to the country"; although the rate of increase of urban population between 1910 and 1920 is generally less than the rate of increase between 1900 and 1910.

Before the discovery of the Germ Theory of Disease, and the proof that typhoid fever and other diseases were due to the introduction of bacteria into the human system, and that these bacteria could be carried by water, food, or air, water supplies were ordinarily obtained from rivers, lakes, or wells, notwithstanding that such sources had in some cases received the sewage of other communities but a short distance from the point where the supply was taken. Thus the city of St. Louis obtained its water supply from the Mississippi River, although other cities had discharged their sewage into it but a short distance above. The city of Lawrence took its supply from the Merrimac, but a few miles below the sewer outlets of Lowell. Water was taken from wells which in many cases were close to cesspools or other sources of contamination. Dilution, filtration, deposition, or a flow of certain number of miles in a river, were supposed to effect sufficient purification. It was recognized, of course, that it was not desirable to take a supply of water from a source that had been contaminated by sewage, but the objection was based upon a sentimental repulsion rather than upon scientific grounds. Water was sometimes filtered before using, but it was mainly to remove objectionable sediment or color.

The discovery of the relation between micro-organisms and disease, some fifty years ago, changed all this, and the subjects of water supply and sewage disposal were brought into close and immediate contact with the subjects of chemistry and bacteriology. Chemical and bacteriological analyses of water and sewage were invoked as guides in answering the question whether a given water was suitable for use, or whether a given sewage could safely be disposed of in a certain manner; and chemical and bacteriological processes were devised for treating water and sewage and removing or reducing the contamination.

The sanitary engineer, therefore, though he need not be a chemist or bacteriologist, must yet know enough about chemistry and bacteriology to be able to understand the processes used in those sciences, and to interpret and use the results.

The problem of water supply is to obtain an adequate supply of suitable water. The future growth of the city and the quantity of water required must be estimated. Seasonal and yearly fluctuations in the source of supply must be studied, and reservoirs provided in such manner that the supply will always be great enough even for an exceptional demand, as in case of a great fire. The waste of water in our cities, by careless use, leakage, and faulty plumbing fixtures, is often enormous, and must be studied, and methods of reducing it provided. Sometimes it is desirable, or even necessary to meter each house supply, so that each householder shall pay for what he uses. Dams, conduits, and tunnels must be designed, to conduct the water to the city, and pumping stations, if pumping is necessary. The water shed must be protected from contamination if possible, or sometimes large plants for filtering or chemically treating the water must be provided. The right of way for the conduit must be bought, and aqueduct bridges built to carry the water over depressions; or pipe siphons installed to carry it underneath. The system of pipe distribution in the city must be carefully designed, based on the principles of hydraulics and the experimental results regarding the flow of water in pipes and conduits. Stand-pipes or reservoirs must be provided at suitable points and elevations.

It is obvious that the sanitary engineer must be familiar with hydrology—the laws of rainfall and of the flow of streams, and the methods of measuring these quantities—with theoretical and experimental hydraulics, and with the theory and design of structures. He should also know how to deal with statistics and to draw valid conclusions from them.

The first municipal water supply was introduced into Boston in 1848 from Lake Cochituate, less than 20 miles distant. The event was celebrated with much rejoicing. But by 1878 the supply was found inadequate, and it was necessary to increase it by going to the Sudbury River, where a series of basins was constructed from time to time. By 1892, even this source was found inadequate, and a new source of supply was sought, this time not for Boston alone, but for the Metropolitan District, by going to the Nashua River, where a large reservoir was created by building a dam with a maximum height of 207 feet. This work required the relocating of 6½ miles of railroad track, completely flooded the sites of several towns and villages, and necessitating the removal of 6 mills, 8 school houses, 4 churches, and 360 houses which had been occupied by 1700 people. The work was completed in 1905 at a cost of $43,287,875.89, and was connected with the Sudbury supply, so that both are available. Provision was also made for still further increasing the supply when demanded.

Other large cities have had a similar experience, particularly those which cannot take a supply from a large river or lake which is almost inexhaustible. Some of the cities on the Great Lakes take their supply from the lake, by laying a pipe or driving a tunnel to an intake some distance out. In such cases, as the water near the shores becomes more and more polluted by the discharge of sewage, it is necessary from time to time to extend the intake further out, or to treat the sewage, or even—as in the case of Chicago—to divert the sewage from the lake, and discharge it into another channel. Chicago, by building the Drainage Canal, discharged its sewage into the Illinois River, through which it flows into the Mississippi,—not to the satisfaction of the cities on either river. The result was serious, and extended law suits followed, to determine claims for damages.

Los Angeles has recently completed an elaborate water supply system, by which the water is brought from the Sierra Nevada Mountains, about 259 miles distant, where the melting snows supply an adequate quantity for many years to come. San Francisco, which had previously obtained its supply from surface and ground waters within a comparatively short distance from the city, both on the peninsula and on the opposite side of the bay, is now beginning works to obtain a supply from the Hetch-Hetchy valley in the Sierras, 190 miles distant.

New York has just completed the largest work for water supply that has ever been executed, in ancient or modern times, by bringing water from the Catskills, 120 miles distant, with provision for still further extension. In connection with this work the Kensico dam has been built, one of the greatest masonry dams in the world, 1850 feet long, with a maximum height of 307 feet above the foundation. Some further reference to this great work is made in Chapter VII.

These illustrations will serve to show the magnitude of works of water supply, and to demonstrate the fact that there will always be a great field for the civil engineer in this branch of the profession.

Of coördinate importance with works of water supply are works for the disposal of sewage. Almost all the water brought into a city as water supply, after fulfilling its purpose, flows away as sewage. Comparatively little is permanently changed into solid or gaseous form. In addition, the sewers must carry a considerable proportion of the rain which falls over the city area, depending upon the ratio of impervious to pervious surface; and there is also sometimes considerable leakage of ground water into the sewers, as well as some leakage out of them under some circumstances. There must in general be a sewer in each street, properly proportioned and laid out at a suitable grade, and in this way the sewage is gathered into main sewers which lead to the point of discharge, or often to a pumping station, or to a plant for treating the sewage chemically, or by filtration, or by bacteriological action, to make it innocuous. Sometimes, in inland cities the sewage is disposed of on land, either without or after treatment, for irrigation.

In addition to the sewerage system itself, the design and arrangement of the sanitary appliances in dwellings and in commercial buildings come within the field of the sanitary engineer. The designs of the water supply and sanitary appliances for a large building, with provision for fire protection and for heating and ventilation, are often very complex.

The disposal of garbage is one of the problems of sanitary engineering. Probably few of us have ever stopped to think what becomes of the ashes and garbage from our homes. The ash man comes at intervals and takes the ashes away. In some cases they may be useful for filling, but if the city is built up, it may be necessary to carry them long distances before a proper place to dispose of them can be found. The garbage must be treated in such a way as to recover, if possible, any valuable ingredients, while the remainder is disposed of by burning, or otherwise, so as to be inoffensive. The problem of its disposal is, by no means, a simple one, and requires chemical, mechanical and sanitary knowledge and experience. In New York City the amount of garbage amounts to about 2,000 tons a day.

An allied subject is that of street cleaning, which forms an important part of municipal administration, and requires great executive ability on the part of the engineer. It is largely a problem of organization, for which an engineering training is an excellent preparation. When Col. George E. Waring, an eminent sanitary engineer, was made Commissioner of Street Cleaning of New York City, some 30 years ago, he introduced engineering methods into this work and set a standard which has been largely followed ever since.

The subject of heating and ventilation has in itself become of late years a specialty, and there is a large society composed of engineers practicing in this field, which is generally considered as belonging to mechanical engineering rather than to civil engineering, as it is intimately connected with the development of power.

The drainage of swamps is not only a problem of reclaiming land for cultivation, but largely one of sanitary engineering, by exterminating mosquitoes. Everyone knows to-day that mosquitoes, which breed in swamps, are carriers of disease, and that yellow fever is caused in this way. Swamp drainage, as a sanitary measure, is sure to increase in importance. The Pontine marshes, in Italy, were for centuries known as sources of pestilence, though the cause was not understood. The conditions in various parts of Europe, due to the presence of swamps, is very serious. Some parts of the Danube valley are almost uninhabitable on this account. It is safe to say that the prosperity of Cuba is largely due to the elimination of yellow fever; and it is very certain that the construction of the Panama Canal was made possible by the efficient work of Surgeon-General Wm. C. Gorgas, who had previously eliminated yellow fever from Havana, in controlling that disease on the Isthmus. Here is an instance of the coöperation of the physician, the administrator, the bacteriologist, and the engineer, and such coöperation is sure to increase.

American engineers are sure to be called upon to assist in sanitary work in other countries. Recently Professor George C. Whipple, of Harvard University, was sent to Europe by the League of Red Cross Societies to study questions of sanitary engineering in various countries.

It is obvious from this description that the field of the sanitary engineer touches at many points the fields of chemistry, bacteriology, and preventive medicine. The sanitary engineer must be informed in regard to the general subject of Public Health, or the control and prevention of disease.

6. *Structural Engineering*

Structural engineering is one of the most important fields for the civil engineer, and it is one of the broadest fields, because structures occur in every one of the branches which have been thus far discussed.

Structural engineering deals with the design, construction, and maintenance of fixed structures; as distinguished from machines, the whole or parts of which are in motion. The railroad, highway, and municipal engineer has to deal with the construction of bridges, retaining walls, etc. The structural engineer has also to design the construction of buildings. The hydraulic engineer deals with the construction of dams, reservoirs, stand-pipes, water towers, movable dams in rivers which are made navigable, and many other structures. The railroad engineer also deals with the construction of tunnels, of coal handling plants, water tanks, trestles. The electrical engineer constructs towers for electrical transmission lines. Further, the engineer builds oil and gas tanks, elevators for the storage of grain, and many other structures.

In problems of rapid transit in cities, elevated railways must be built, or subways underground. These structures call for innumerable problems in design, involving the computation of the pressure of the earth and the arrangement and size of the walls, roofs, and columns.

Structural engineering is sometimes supposed to deal mainly with bridges. This, of course, is a large part of the subject. There are many kinds of bridges, varying from the simple beam which spans a short opening to enormous cantilever bridges, arches, or suspension bridges, like the structures over the East River, the St. Lawrence River, or the Firth of Forth. There are movable bridges of many kinds, some of which revolve about a central pier, some of which are lifted bodily into the air, some of which are bascule bridges, either single or double, which revolve about horizontal pivots at the ends. Some of these structures are of great complexity and size. And while they are designed by means of methods and formulæ based upon the principles of the strength of materials and the laws of mechanics, these formulæ are often far from accurate, so that judgment and experience are qualities of the highest importance. The failure of such structures may involve great loss of life and property.

For many years the bridge of longest span in the world was that over the Firth of Forth in Scotland, which has two spans of 1,710 feet each. When a bridge across the St. Lawrence at Quebec was proposed, the engineer in charge decided to surpass the Forth Bridge in dimensions, and designed a structure with a span of 1,800 feet. The bridge which he designed, however, collapsed before it was completed, owing to faults and carelessness in the design, involving the loss of 74 lives. Many tons of steel now lie at the bottom of the St. Lawrence River, the wreck of this first Quebec bridge. After this accident, a second bridge of the same span was designed by other engineers. While the first bridge was planned to be erected by building out over the river from two piers near the water line, the second bridge was designed to be erected by building out only part way and supporting upon the ends of the cantilevers so constructed a central span built separately and hoisted from pontoons into its final position resting on the cantilever arms. While this central span was being raised, the support at one corner gave way and the entire span was precipitated into the river, where it now lies. A new central span was constructed in its place and was successfully put into position, and the bridge is now in operation. The failure of the central span involved the curious paradox that by increasing the material in a structure or a part of a structure, the strength could be decreased. These two failures have shed much light on certain problems in bridge construction. Recently a suspension bridge with a span of 1,750 feet has been proposed, to cross the Delaware River at Philadelphia.

The construction of high buildings affords another important example of structural engineering. It also illustrates the relation between engineering and architecture. The completion of a building involves really three distinct branches; first, its construction; second, its arrangement from the point of view of convenience of use; and third, its architectural appearance. The architect is generally concerned more with the last two of these functions than with the first, except for buildings of a common type. The first, however, is fully as important as the others, if not more important; and the modern skyscrapers, are really engineering structures of enormous magnitude. The building of such structures again illustrates the necessity for experience and judgment as well as theory. The mere determination of the loads to be assumed on such a building is very uncertain. Shall a building be designed on the supposition that every floor is simultaneously loaded with the maximum load that can never come upon it, and that at the same time a tornado is blowing, in which the wind has the greatest velocity ever recorded; or shall some allowance be made, and if so, what, for the fact that these circumstances would never occur at the same time? This illustrates the fact that structural engineering, although it may appear to depend upon formulæ and theories which can be worked out mathematically, is in reality in a large measure uncertain, on account of the uncertainty of the data to be assumed. There are also uncertainties regarding the workmanship and the effect of workmanship upon the stresses which will exist in the material. An error of a fraction of an inch in the length of a member of a bridge may make a very great difference in the stresses existing under a given load. A blind adherence to formulæ is just as bad as a blind trust in experience. The two must be combined with judgment and the ability to get the results desired.

High structures have had a fascination to mankind from the earliest times, since the building of the Tower of Babel or earlier. The Colossus of Rhodes, a bronze statue 105 feet high, erected about 280 years before the Christian era, is said to have required 12 years in construction, and was regarded as one of the seven wonders of the world. The Pyramid of Cheops, with a height of 484 feet, was of much greater antiquity and exceeded in height all other structures erected by man up to the year 1240, when the spire of the old St. Paul's Cathedral in London reached a height of 520 feet; this was destroyed in 1561. The Cathedral of Cologne was completed in 1880 with a height of 511 feet, and the Washington Monument in 1884 with a height of 555 feet, and this was the highest structure until the construction of the Eiffel Tower, completed in 1888, which reached a height of 984 feet. Soon after this time, however, the construction of skyscrapers began in the United States, culminating in the erection of the Woolworth Building, which has 51 stories and reaches a height of 792 feet, being the highest structure in the world with the exception of the Eiffel Tower. In New York City alone there are 35 buildings above 300 feet in height and 5 over 500 feet in height. The frame-work of such a building is, of course, the province of the structural engineer.

The recent great extension in the use of concrete has greatly enlarged the field of structural engineering. Many structures which in the past would have been made of steel or wood are now made of this new material, which acts according to laws determined by a combination of theory and experiment, and very different from those governing the use of the older materials. Indeed, some structural engineers now make a specialty of concrete work, which is used in the construction of bridges, even those of considerable span, and in buildings of all kinds.

Grain elevators afford an example of a kind of structure which may even become a specialty in structural engineering. A former student of the writer happened to be drawn into this kind of work, and is now engaged as a consulting engineer in the design and construction almost exclusively of grain elevators in all parts of this country and in foreign countries as well.

It will be seen from this outline that the field of structural engineering is very large and is constantly expanding. It is one of the specialized branches of engineering, and the specialist in it finds opportunities for the application of his ability in connection with all branches of engineering and constructive work.

7. *Municipal Engineering*

This is not a distinct branch of the profession, but is a combination of several of those that have been described. The business of a municipal corporation, like that of any other,—or even more so than that of most corporations—is largely engineering. This is evident upon consideration, and it is further indicated by the fact that under the city manager form of operation the city manager is often, if not in the majority of cases, a civil engineer. The first city of large size to adopt this form of operation, Dayton, Ohio, chose as city manager Mr. H. M. Waite, whose training and practice had been that of a civil engineer; and his successor, Mr. J. E. Barlow, is another. Both are former students of the writer.

The municipal engineer generally has charge of all city engineering work, including water work, sewers, sewage disposal, bridges, streets, roads and pavements, and sometimes urban transportation, generally with assistants who are specialists in different departments. The city engineer should therefore be a man of broad outlook, and large experience. His work is very varied. If he needs special advice on any of his problems, he calls in consulting engineers who are specialists; but he must have a broad grasp upon all of his problems.

The position of city engineer is often not recognized as it should be, politics often governs the selection of the man, and he is subject to the vicissitudes of political changes. Hence the postion is not generally sought by engineers of eminence. Yet there are notable exceptions; and not infrequently the city engineer is the official least likely to be affected by a change in administration, holding his position continuously no matter what party is in power. The late William Jackson, of Boston, was such a man, having been continuously in the employ of the city for 37 years, the last 25 years as City Engineer.

The city engineer frequently has a leading part to play in city planning, which has to do with the laying out of streets, the restriction of occupations to certain districts, and city improvements in general. In such ways the city engineer often has the opportunity to do things of the greatest benefit to the city, though they may not be fully appreciated at the time. The director of City Planning of Rochester, N. Y., Mr. E. A. Fisher, for many years city engineer, has recently presented a plan whose adoption he urges, by which the city should purchase the abandoned Erie Canal, which purchase is provided for by law; and he shows that by acquiring the canal the city will become possessed of a right of way strip through the city which can easily be utilized for an urban rapid transit line for passenger traffic, and which can also be made to connect with all the railroads entering the city, and may so serve for freight distribution and collection as well. By this plan the transit problem will be practically solved for Rochester for many years to come, and if justice is done, Mr. Fisher will be looked upon as a public benefactor.

So important is the work of the municipal engineer that a separate engineering association, The Society for Municipal Improvements was organized in 1894 and now has some 500 members, the majority of whom are engineers.

The work of the city engineer deals not only with construction, but also with maintenance. It also has to do with economic questions, such as methods of assessing taxes for improvements, as for streets and sewers, methods of condemning land, etc.; and so it contributes to the cultivation of breadth of view on the part of the engineer.

8. *Valuation of Properties*

Within the last two decades, what is practically a new branch of engineering has been developed, namely, that concerned with the valuation of public utility and other properties. This cannot be said to be a branch of civil engineering any more than of electrical or mechanical engineering, for engineers of all kinds are called upon to engage in it; but as civil engineers have gone into it to a large extent it may be referred to here.

For many years it has been necessary to have appraisals made of the value of properties, either for purposes of raising money by the issue of securities, or for purposes of sale. During the last few decades, however, during which time the public utilities have been subject to regulation by public commissions, which have the power to fix the rates which those utilities shall charge for their service, it has become necessary in many cases to ascertain the fair value of the properties upon which they should be entitled to earn a fair return. This question has become a leading one in the economic discussion of the day and before courts. It is a question of economics and justice, as well as of engineering. In this field, engineering comes into contact with accounting, with economics, with law, and with the general question of the relations between the utilities and the public. It has required the services of a great many engineers in ascertaining the physical value of the properties, requiring an inventory of the property and the fixing of a fair price for each element of it. It also involves the question as to what is the value of a property completed and in operation as compared with the value of the physical items which make up the property, or the "bare bones" of the plant.

This work requires the possession of a judicial attitude of mind and of the ability to analyze accounts, and to deal with economic questions of a somewhat intricate nature.

Civil engineers have taken part largely in this work, and it offers an interesting and remunerative field for an engineer possessed of the necessary experience and knowledge, and with the proper temperament. The

Interstate Commerce Commission has for several years been engaged in finding the physical value of the railroads of this country. In the prosecution of this work the services of 1,400 engineers have been required by the Commission. Furthermore, the public service commissions of the various states generally have engineering departments in which there are engineers, who not only have to deal with questions of construction and maintenance and the approval of plans for new work, but who also have to make appraisals where needed for purposes of valuation. The writer has for a number of years given a course on this subject in Harvard University, and in some other institutions instruction is given in it. It is not a proper field for a young and inexperienced man, except that a good many such men are often required in making the inventory of physical material and in collecting the other data, historical and otherwise, upon which a proper final judgment is to be passed. The subject offers a good field, however, for men of experience in construction who can deal with the economic problems which it presents.

CHAPTER III

QUALIFICATIONS NECESSARY OR DESIRABLE FOR THE CIVIL ENGINEER

For the successful practice of Civil Engineering, as of other occupations, specific qualifications of a professional and of a personal kind are requisite, or if not absolutely necessary, are at least desirable. Professional qualifications are those qualities or acquirements which affect mainly his *knowledge*, and which, therefore, supply the basis for his intelligent dealing with the problems to be solved. Personal qualifications are those qualities which fit him to apply his knowledge properly, economically, and effectively, and so to accomplish the result which his professional knowledge and skill indicate to be desirable or necessary. The two kinds of qualifications do not always go together, yet their union is necessary for the highest success. An engineer may have great professional ability, yet on account of the lack of some personal quality, such as tact or promptness, may be a miserable failure in certain kinds of work. On the other hand, an engineer possessed of all the personal qualities necessary, but lacking professional knowledge, such as of the properties of the materials to be used, or the laws of nature applicable to the case, may find his plan or his structure a costly failure.

Professional Qualifications

Remembering that civil engineering consists in applying the laws, forces, and materials of nature, economically, for the use and convenience of man, it is at once evident that the knowledge, or professional qualifications of the engineer, must include:

1. A knowledge of the forces of nature, and of the laws governing them; in other words, a knowledge of natural science, logic, and mathematics.
2. A knowledge of the materials applicable in construction.
3. A training in those branches of knowledge which have to do with the *economical* adaptation of means to ends.
4. A perception of the true relations of things, or a sense of proportion, which will indicate what measures or projects that are physically possible will really conduce to the *use and convenience* of man.

1. It will be abundantly evident, from what has been presented in the last chapter, that engineering is not an abstract science, which can be followed by a recluse in his study, but an intensely practical affair, indeed, a kind of business. The engineer must be a business man, not a theorist, and must conduct his work on business principles. As applied to any contemplated project, the work of the engineer consists, in most cases, of four parts: first, to determine whether *anything* should be done, and, if so, what; second, to design and formulate the means to be employed in doing it; third, to select and test the proper materials; fourth, to carry the actual work through its various stages

to completion. It is therefore clear that the engineer should be scientifically trained, and should possess a knowledge of natural science and mathematics. Different branches of science are required in varying degrees in the different branches of the profession, but every engineer should know, and know thoroughly, the fundamental principles of chemistry, physics, mathematics, and mechanics, with such knowledge of geology, astronomy, and biology, etc., as may be requisite for his particular specialty. Moreover, in order to know these subjects as he ought to, and to be able to draw his conclusions with accuracy, he must be possessed of the true scientific spirit and attitude of mind, loving the study of science for its own sake as well as for its applications and the material benefit they may bring him.

It is particularly important that the engineer should possess the scientific attitude of mind. By this is meant the attitude which leads him to approach a problem entirely without prejudice, without preconceived ideas, intent only on seeking the truth, the whole truth, and nothing but the truth; and the willingness to accept the truth, when found, even if it is unpalatable or may lead to the abandonment of the project on which he is engaged. He must even be without ideals, except the simple personal ones to do right, to injure no one, to judge not, and to do what proves to be best under the circumstances. He must first of all clearly perceive the problem which is to be solved, in its full extent, and without neglecting to see all the elements involved, in their proper proportion. Then he must assemble all the facts which have a bearing upon the solution. Then he must apply the proper scientific principles to those facts, and by a process of logical reasoning arrive at the truth. The idealist too often, if not generally, starts out with a preconceived idea of the result which he desires to reach. He omits or minimizes facts or conditions which conflict with those ideals, and not seldom simply succeeds in persuading himself that he has demonstrated the truth of his preconceived ideas. Such a course is fatal.

It must not be inferred that the engineer should have no imagination, for this quality, as will be hereafter shown, is one of the most important for the engineer. The point is, that he must not approach his problem with any preconceived ideas or ideals except the simple ones already stated, which, indeed, should be the ideals or aims of every man at all times and under all conditions.

Especially important is it that the engineer should have a logical mind so that he may reason logically from facts and principles. In some callings this quality may not be so important; for instance, in some branches of business, where if a man reasons illogically and makes an error the injury will be suffered by himself alone. But in engineering, where illogical reasoning may result in the collapse of a bridge, a building, or a dam, with great resulting loss of life and property to innocent persons and not to the engineer, or in the failure of the project, such as a railroad or an irrigation scheme, by which many innocent investors may suffer great financial loss, the responsibility of the engineer is such that logical reasoning is of the first importance. The engineer must, therefore, as in the profession of medicine and the law, where similar responsibilities are present, be a logical man, and trained in the principles of logical thinking.

The civil engineer must also be proficient, to the necessary extent, in mathematics. He should know thoroughly the fundamental principles of that branch of learning through the calculus, that is to say including arithmetic, plane and solid geometry, algebra, trigonometry, analytic geometry and the differential and integral calculus. But this does not mean that he must necessarily be what would be termed a fine mathematician, for many eminently successful engineers have been very far from this. Indeed, there are real dangers in excessive proficiency in mathematics. Mathematics and logic comprise the abstract sciences, that is to say, the sciences which may be reasoned out in the abstract, in the solitude of the study, without the need of experience or contact with the concrete problems of life. Mathematical truths and processes may be perceived by the mind without experiment. The data being assumed, or the quantities to be dealt with being represented by letters, the processes of mathematics are rigidly correct, and enable necessary consequences to be deduced from those data.

Mathematics is a somewhat curious subject of study. It is a machine, and works with unerring accuracy.

Into one end of the machine are put the data, the crank is turned, the machine works, and the result comes out with absolute correctness. But this correctness depends entirely upon the data. It is only really correct if the data are correct. Put in correct data and a correct result will be reached; put in incorrect data and the result will be correspondingly incorrect. Moreover, a small error in the data may lead to a large error in the result; just as a small divergence from a straight line, when a railroad train takes the switch at the beginning of a curve may shortly direct the train in just the reverse direction. The mathematical machine is very interesting, in construction and operation, and the danger is that the student of mathematics may become so absorbed in its construction and operation that he loses sight of the importance of the data. The engineer, however, must be sure that his data are correct, he must see all the elements of the problem, and must therefore see to it that he puts the mathematical machine to work upon *correct* and *complete data.* If the data are either incorrect or incomplete, the most elaborate mathematical analysis may be worthless. Yet the study of abstract mathematics tends to lead the mind away from a proper attention to data; it tends to educate away from common sense. This is the reason why the finest mathematicians sometimes make the poorest engineers. The engineer must look upon mathematics merely as a machine, or tool, which, with judgment, common sense, and clear purpose, he uses for the end in view. He must never be mastered or governed by it, but must make his own intellect its master. So in deductive logic, the laws governing correct reasoning are abstract and independent of actual conditions. Inductive reasoning is based upon a collection of facts obtained by other means, as by observation or experiment, but the processes of reasoning employed are abstract, like those of mathematics. But engineering deals with the facts and problems of actual life, in which data are uncertain, exactness impossible, conditions shifting and variable, and premises generally more or less doubtful. The engineer must perceive the relation of these uncertainties to his problem and the results of his analytical deductions. In studying mathematics, as John Stuart Mill said, the mind must not "go to sleep over mathematical symbols."

For the engineer, therefore, mathematics and logic must be studied as tools, and with regard to the shifting and uncertain character of the data. The excessive or improper study of mathematics in the abstract, by emphasizing the process rather than the broader problems which these processes aid in solving, may therefore cultivate an abstract turn of mind which makes the student impractical or visionary, and distorts his point of view, leading him to suppose that a multitude of figures or equations constitute an accurate solution, rather than to cultivate the power of gaining a clear and practical view of the problem as a whole. In other words, mathematics studied in the abstract tends to diminish that most important faculty for the engineer, or, for that matter, for any one who deals with the actual problems of life, common sense. This is the reason why so many eminent engineers have known little of mathematics, while they have invariably possessed common sense in high degree. Nevertheless, mathematics is one of the most important tools of the engineer, and he should have a mathematical mind, that is, a mind capable of perceiving and utilizing the relations with which mathematics deals. He should certainly have a "head for figures." The great engineers who have not been mathematicians have possessed such minds, and in many cases would have made good mathematicians even in the abstract sense, if they had been trained in this direction.

The object of the preceding remarks has not been to discourage the cultivation of mathematics, or to disparage the great usefulness of that wonderful science, but to urge the point that the engineer must not allow his study of mathematics to become too abstract, and must continually perceive the uses and the practical bearings of the science. If he does not do this, but allows the abstract mathematical point of view to dominate his mind, he may become a fine mathematician or theorist, but he will probably find himself always occupying subordinate positions, doing the routine work of calculation, or in other words, turning the crank, for those who have the greater grasp which enables them to tell him what to do. Our industries are full of men of this class, who are employed to do the routine work for the leaders who have the vision, imagination, common sense, and initiative.

2. No work of engineering construction is carried out except by the use of some of the materials of nature, such as steel, wood, stone, cement, brick, paint, etc. These materials vary greatly in kind and quality, and some may be suitable for the purpose in view while others may be entirely unsuitable. One of the most important problems of the engineer is to determine the kind of material which is suitable for his purpose, and a second is to select that quality of material, of the kind chosen, which will be most economical. Again, he must know how to test the materials to be used, in order to assure himself that he obtains the desired material and so that he may reject materials that are inappropriate or do not conform to his specifications. For these reasons, a knowledge of the materials available for engineering structures or machines is of great importance. This requires a knowledge of chemistry, physical properties, and methods of manufacture.

Suppose a bridge is to be built. It may be of steel, wood, stone, or concrete, and if of steel it may be of steel cables or of rolled steel shapes, of carbon steel or nickel steel. The design and form will depend largely upon the material; and the resulting economy, durability, cost of maintenance, appearance, and suitability for its purpose all depend upon the material selected. The theoretical engineer or mathematician might be able to make the necessary computations for any material which might be selected, but far more important is the professional and practical knowledge, together with the experience, which is necessary in order to make a proper choice of material. Further, in order to make sure that suitable material specified is procured, certain physical and chemical qualities, such as strength, ductility, hardness, percentage of foreign elements like phosphorus, sulphur, etc., must be specified, and tests made on specimens or full size pieces, to ensure the desired results. All this calls for specialized knowledge, and some engineers confine themselves to giving advice and making tests of materials.

A large proportion of the failures of engineering works, very likely a majority, are due to improper material. In some cases an entirely different material should have been used, while in others the particular material used, though proper in kind, was defective in some manner. Sometimes the fault lies in the workmanship, by which a proper material has been injured in the process of manufacture or in the handling and placing.

So important is this branch of the science of construction that a national society has been in existence since 1898, which deals with it, known as the American Society for Testing Materials. Also, an international society, the Internationl Society for Testing Materials, and embracing in its membership representatives of over twenty nations, has been in existence since about 1882, and holds extended conferences every few years for the discussion of methods of testing, standardization of tests and specifications, and the discussion of problems relating to engineering materials.

The technique of this subject is difficult and complicated, and always involves more or less uncertainty. For instance, it has long been recognized that phosphorus tends to make steel brittle when cold, and should be limited in amount in steel for structural purposes. But just where should the line be drawn? How much and no more is allowable? The answer cannot be stated with definiteness, yet it is desirable that agreement should be reached, in order that specifications should be uniform, rather than that each engineer should follow his own ideas. The same applies to many other requirements, both chemical and physical. The work of the societies above named is done through the medium of committees, on which both manufacturers and users are represented, and consists largely in formulating standard requirements which conform to experience and good practice, which are generally adopted, and which are modified from time to time as experience and the progress of the art may indicate.

This branch of the profession affords an illustration of the remarks above made with reference to mathematics, for mathematics has little to do with this important part of the work of the engineer, which is governed mainly by experience, common sense, a knowledge of chemical and physical properties, and the mechanical ability to devise means and methods for making tests which will adequately represent those properties.

3. The third professional requisite for the engineer is that which will enable him to secure *economy.*

This is an essential for good engineering. Indeed, the engineer has been described as a man who makes two blades of grass grow where one grew before, but another definition more applicable here is that he is a man who does for one dollar what any fool can do for two. Almost anyone can either do engineering work, or hire it done; but in engineering, as in other things, few can do just the right thing, and in the most economical way. It may sound materialistic and unidealistic, but the question of economy properly comes into almost every affair of life, even into charity.

It is comparatively easy to build a bridge, although it requires skill and knowledge, but more important than the question—how to build it—are the questions—where to build it, when to build it, and whether to build it at all. If a bridge is built in an improper location it may not only fail to serve its purpose properly, but great expense and inconvenience may result. If an irrigation or a hydro-electric project is embarked upon without a careful consideration, not only of the cost, but of the market and all the other economic elements entering into the problem, it may prove unprofitable and the investors may lose their money.

Not only must estimates of cost be made in connection with almost every engineering project, but the study of engineering economics often requires that facts be compared which can only be expressed in incommensurable terms. Elements must be weighed against each other which are entirely different in character. For instance, if we ask which is the greater, 6 feet or two meters, there is no difficulty in giving an answer; but if we ask which is the more important, 10 feet or five dollars, or which is the more valuable, truthfulness or beefsteak, the reply is not entirely obvious. These illustrations are not fanciful. In engineering work it is frequently necessary to make comparisons between things which have to do with our physical well-being and those which have to do with our economic, or even with our moral or spiritual well-being. Although these things are incommensurable, they must be compared and an opinion formed from the comparison. In planning a station for a subway for urban transportation, one design may require passengers to walk on the average a certain number of feet and to climb a certain number of stairs, while another design may cost more but require less walking and less climbing. Here a comparison must be made between dollars and feet, or between cost and physical exertion. Engineers have sometimes endeavored to meet such cases by a fanciful endeavor to express the comparison in commensurable terms. It would be possible perhaps to compute the value of the shoe leather that would be saved in a year if all the passengers using the station saved the given distance according to the more expensive plan and to compare this saving with the interest on the added expenditure. It is not infrequent in problems involving rapid transit, to compare the cost with the time saved. One plan may cost a certain sum more than another plan, but it may involve a saving, let us say, of three minutes for each passenger. Some people endeavor in such a case to compute the total saving in time by multiplying three minutes by the total number of trips in a year, alleging that this is the total time saved; and then estimating the value of this time on the basis of the average wage or earning power of a passenger. In this case it is endeavored to make the comparison between dollars and minutes by reducing them to commensurable terms.

Such comparisons are generally made by those who find their judgment unable to deal with the subject in any other way—who cannot compare except by measuring or weighing as they have been accustomed to do. Such persons often do not realize that the comparisons they make in that way may be entirely deceptive. A Japanese, riding on the New York subway, and being told that by making certain changes from one train to another a saving of fifteen minutes might be made in going from one point to another is said to have asked his informant—"And what do you do with the fifteen minutes?" If spent in the train it is not necessarily lost, but may be utilized, if only in meditation, like any other fifteen minutes in the day. Also such comparisons between cost and saving of time often make the mistake of not considering whether the individuals who make the saving in time are the same individuals who would bear the increased cost.

No special directions or specifications can be given with reference to the economic sense which must be possessed by the engineer. It may be called a special sense and involves the use of judgment, and above all things, a well balanced mind. If it is urged that an escalator or moving stairway should be placed at a subway station so that people would not have to walk upstairs, and if the inconvenience suffered by an aged or infirm person in climbing the stairs is portrayed in vivid colors, it is necessary to decide how much consideration should be given to such an argument, and it may also be inquired whether such aged or infirm persons have elevators in their own houses, or why they go down town at all, or how far they walk or climb in the department stores. If safety appliances are urged for railroads or industrial establishments because loss of life sometimes results if they are absent, it is necessary to consider what expenditure is justifiable in order to prevent the loss of a certain number of lives per annum; in other words, what is the value of a human life to the public, or to an employer. There will always be found people who seem to think that any expenditure is justified in such a case provided that expenditure is paid by somebody else.

The economic sense, therefore, is intimately connected with the fourth and last of the professional requirements which have been named as requisite for the engineer.

4. This requirement is, in brief, a sense of proportion, or a proper mental balance.

This is an essential requirement in any walk of life, but especially in the case of a man who has to do with the consideration or management of large enterprises. The ability to observe correctly, the faculty of getting all the facts and of knowing when all of the pertinent facts have been collected, the ability to reason from those facts, the possession of conservatism and calmness of mind, the lack of sentiment, the absence of a stubborn persistence in holding to a previously formed opinion in the face of proof of its error, and the faculty of seeing different things in proper proportion and weighing them fairly against each other are all essential to a well balanced mind. An engineer may possess technical knowledge and great mathematical ability, but without balance he ought never to be a leader, and his judgment in large matters will be worth little or nothing.

This faculty can be cultivated like any other. To cultivate it requires reading, study, meditation and contact with other men. The study of history and biography are especially valuable, particularly the study of human failures. The engineer may always learn more from the study of failures than from the study of successes, if he will carefully consider the causes of the failure; and if he has the faculty of assimilating that study in such a way that he can make his own the experience of other men, he can go far to develop a sense of proportion. Most men learn only by experience, and while experience is the best teacher, it is a very costly one. The advice given by old and experienced men may be most valuable, but it is too often disregarded by the young, who think they know it all and who can only learn by their own mistakes, and so the old continue to warn and to advise and the young continue to disregard and to suffer.

As the engineer deals with the applications of science to the affairs of men, he must be above all a practical man. He must not be a pure theorist, a dreamer or a visionary. He must see in a mathematical formula a meaning and not simply an accumulation of letters. He must know his scientific principles, but he is not an engineeer unless he can apply them.

The engineer must also have a business sense, remembering that engineering is not simply utilizing the forces of nature for the benefit of man, but utilizing them economically and properly. His work requires financial and business ability, combined with a clear insight into the practical relations of things. If he is to build a railroad, he must study the manufacturing and economic conditions affecting the country through which it is to pass; he must consider the traffic on existing roads, the relative importance of the cities, whether there is a possibility of increasing the agricultural or manufacturing product, whether his line should run in a comparatively straight line between two towns or whether it should be diverted in order to tap smaller towns or whether those smaller towns should be reached by branches from the main line. He should have the large view. He has the opportunity to do worse than waste the money of his employers.

After his work is decided upon, he must draw up contracts for its execution, make monthly estimates of how much has been completed, certify payments to the contractor, settle disputes, and in general attend to all the business, excepting legal matters, connected with the carrying out of the enterprise. He must be an organizer, and must know how large a force is necessary to carry on the work, and how to dispose it to the best advantage and with the greatest economy. He must, therefore, be a student of men and must know how to get along with them smoothly and to get the most work from them.

The engineer not only applies the materials and resources of nature, but he must know how to conserve them. The natural resources of this country are being wasted in an unexampled manner. Our forests have been largely destroyed and our fuels are being rapidly used up. Not only in applying the materials and forces of nature to the use of man, but in conserving them so far as is possible so that they may serve future generations, the engineer acts as the main element in the progress and permanence of civilization.

Personal Qualifications

In considering the personal qualifications which an engineer should possess it is difficult to make a distinction between those which are particularly necessary for the engineer, and those which are necessary for success in any field of endeavor. Such qualifications as character, promptness, tact, good manners, patience, perseverance, system, power of concentration, self-confidence, respect for others, and many others that could be named, are requisite for the highest success in any field. There are some, however, which, while also requisite to greater or less degree in any field, may be specially mentioned as desirable for the engineer. These are the following:

(1) Judgment
(2) Balance
(3) A trained mind
(4) Experience
(5) Initiative
(6) Good health
(7) Knowledge.

(1) *Judgment.* Judgment is one of the most important qualifications for any man. It is especially so for the engineer who has habitually to decide between different projects or different ways of doing things. Its importance to him cannot be over-estimated. It can be acquired but little through a college course, but comes mainly from experience and an intuitive ability to see straight.

(2) *Balance.* The importance of balance has been already referred to. It consists in ability to see things of different kinds in the right proportion, neither exaggerating the importance of unimportant things, or minimizing the importance of important things. It cannot be measured and the writer can give no rules for its acquirement other than those which have been briefly mentioned above. A balanced man must be unprejudiced. He must have the mental courage to

arrive at any conclusion to which the facts necessarily lead. Personal honesty is not a guarantee of balance. As Lecky says, "There is such a thing as an honest man with a dishonest mind. There are men who are wholly incapable of willful, deliberate untruthfulness, but who have the habit of quibbling with their convictions and by skillful casuistry persuading themselves that what they wish is right." The balanced man does not pursue impractical ideals. He does not start out by assuming the object at which he wishes to aim. He realizes that he cannot determine upon the aim until he has studied the facts and found out what is practicable. He is not the slave of any moral rules. He realizes that every virtue, if misapplied, may become a vice, or as Shakespeare says:

> "Virtue itself turns vice, being misapplied."

He realizes that circumstances alter cases—he is not a slave of sentiment. He realizes the necessity of compromise, and that if he cannot get what he thinks is the best, it is generally better to get the best thing possible rather than to get nothing. He realizes that the most honest and well intentioned men may be the worst advisers and may do more real harm than the self seeker. The French have a witty saying that "Virtue is more dangerous than vice, because it is not subject to the restraints of conscience," and there is an old saying quoted by Cicero that the "extreme of right is the extreme of wrong."

Mental courage, or the ability to face and accept unpalatable conclusions is essential for balance. The balanced man is calm and quiet in speech, not argumentative, and not disposed to express his opinions with dogmatism. He realizes always the limitations of his own knowledge and the uncertainties surrounding every problem with which he deals, and he is not afraid to alter his opinion when new facts which justify it come to his attention.

(3) *A Trained Mind.* The engineer should have a trained mind, that is to say, a mind which functions logically and properly when directed to any subject that it is necessary to consider. This means, as frequently expressed, the ability to think straight. The man with a trained mind is possessed of a machine which he can direct to any problem that comes before him. When directed to such a problem his mind will know how to attack it, where to get the facts that are requisite, when and where to get the advice and assistance of other men, and will be able to arrive at correct conclusions. The man with a trained mind is a safer man, even in dealing with a problem that he has never thought of before, than the expert in that subject if without a trained mind.

A trained mind knows how to study. It can take up a subject that it has never before approached and it knows how to go about it to master it. The engineer has to deal with so many different kinds of subjects, and so many different considerations enter into the solutions of his problems, that without a trained mind he becomes a mere routine underling, simply carrying out the directions of others.

(4) *Experience.* Experience is necessary for the engineer. The young engineer must be prepared to spend years gaining by experience the knowledge of materials and of methods of handling men and doing work that are necessary for his later success. There is a great difference between men in their ability to assimilate experience. Some can do so but slowly and require to learn everything by paying for it at a high price. Others can assimilate the experience of others as if it were their own. For the cultivation of experience, as above stated, a study of history, biography and engineering failures are especially valuable.

(5) *Initiative.* The engineer must have initiative. He is often called upon to make a quick decision, to meet a new problem, or to do something that he has never done before. He must be resourceful. He must not depend too much on books, but must realize the limitations and even the danger of mere book learning.

(6) *Good Health.* Good health, while not essential, is a very desirable quality for a civil engineer. His work, as already stated, is largely in the open air. He cannot gain the necessary experience in engineering construction without as a rule undergoing some physical hardships, and often submitting to exposure. Good health will be a great asset to him. It can be cultivated, of course, by abstemiousness, regular habits, temperance and self-restraint.

(7) *Knowledge.* It may seem strange to put knowledge the last on the list of the qualities requisite for the engineer, and yet John Locke stated the objects of education in their relative rank as follows: 1, virtue; 2, wisdom; 3, good breeding; 4, learning. Our colleges, and even our usual habit of mind, place learning in the wrong position. It is really subordinate to many other things, and while necessary for the engineer, as will be discussed in the chapter on Education, it will not alone go very far to make him successful. It is a requisite, but without the other requisites it is of minor importance.

CHAPTER IV

EDUCATION OF THE ENGINEER

The engineer must be educated in the fundamental principles which underlie the practice of his profession. He must get this education either in the college or technical school or out of it. It is possible for him to get it in either way. Probably a majority of civil engineers have not had the benefit of a college technical training, but they have been men possessed of unusual brains and common sense, and with the ability to study by themselves, like Abraham Lincoln, who had less than three months of schooling, all told, and like Robert Stephenson, who had less than six months in college. A technical college education, however, is a great advantage, and at the present time is almost a necessity, provided the student can take advantage of what it offers. It offers only an opportunity. The college cannot make a man an engineer, but it can afford the opportunity to gain that knowledge and discipline which will enable him to advance in his profession much more rapidly than he could without it. President Draper finely expresses the value of a higher education when he says: "With an independent, sane, balanced character, having the elements of success anyway, the advantage of a college training cannot be overestimated."

The first engineering school in this country was the Rensselaer Polytechnic Institute in Troy, which was organized in 1824. The Lawrence Scientific School and the Sheffield Scientific School were organized in 1847, and these were followed during the next twenty years by the Massachusetts Institute of Technology in 1865, and some others. Since that time, the number of schools at which an engineering training may be obtained has greatly increased, and almost all our Universities have engineering departments.

In addition to a technical engineering education, it is, of course, extremely desirable that the engineer, like any other professional man, should have an acquaintance, and not a superficial one, with history, language, and literature, with economic and social problems, and with the natural sciences. He will not get this acquaintance properly without discipline. He will not get it by taking college courses which he considers easy, and doing just enough work in them to get through. The true object of education cannot be attained without effort. When the work of a student is easy for him, it should be changed. It should always be within his powers, but it should require continued effort. The easy path does not give discipline; it is the steep and rugged path which requires the effort that develops the powers of mind and body. And this is not, as a rule, the path chosen by college students.

The case is different in the professional school. There the young man, if he has good stuff in him, seems to realize that he is laying the foundations for his life work, and he works with energy and application. It is not uncommon to hear young men who have gone through the college of arts and the professional school say that they did not work in college, but only began to work when they reached the professional school. It should not be possible to make such a statement truly. The college should require work just as much as the professional school, though of a different kind. The late General Francis A. Walker, long President of the Massachusetts Institute of Technology, comparing the Institute course with the usual college course, used to say that "the Institute is a place for men to work, not for boys to play." The same *ought* to be true of the college.

When Robert Stephenson's friends, observing his fine mental qualities, urged his father, George Stephenson, to give him a college education, his father said that it was not his wish "to make his son a gentleman." He added "Robert must wark, wark, as I hae warked afore him," indicating clearly his impression that the college course did not mean "work"* Nevertheless, he sent Robert to the University of Edinburgh for one term, or a little less than six months, which was all the college education that this man, probably the most noted engineer of the last century, ever received; but he knew how to study and did study almost every spare minute. In college he was "resolute in his attendance at lectures, and declined to enjoy for an hour the so-

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* Some wit has given a definition of the term "college-bred" as "a four-years' loaf."

ciety of a friend who paid him a flying visit, in order that he might be present at the address of the Professor of Natural Philosophy." His biographer remarks, regarding the University of Edinburgh at that time, "brilliant as the assembly of professors in Edinburgh then was, the educational system of the University was faulty and the students were allowed to pursue their own courses, without discipline, and in some cases without encouragement." This seems to justify the father's impression, and the biographer has mentioned the very thing which justified it, when he said that the students were "allowed to pursue their own courses without discipline." But even this could not spoil Robert Stephenson, of whom his biographer says, "in study he was perhaps intemperate, but in his diet he was habitually spare and moderate." All through his life, as we read of it, we find him studying, taking lessons at one time in Mineralogy and Assaying, preparatory to going to South America as manager of a mining company at the age of twenty-one; studying Mathematics, Physics, and Mechanics at every opportunity; and in this way laying the foundations for his success, even without a college education, either in arts or in engineering.

Engineering is a profession, and the students of engineering are professional students. If they take a college technical course, they should be imbued with the professional spirit and should not be permitted to indulge themselves in the lax methods so common among college students who are candidates for the A.B. degree.

The professional school, however, deals as a rule only with professional subjects, or those intimately related to them. How, then, is the engineer to acquire the general knowledge of language, literature, history, economics, etc., which is necessary in order that he may be a broadly cultivated man, able to meet members of any profession on equal terms?

Training for the other learned professions, divinity, law, and medicine, has generally required students to take a college course in arts, or part of such a course, before entering the professional school, recognizing the fact that the professional man should have broader training than in the details or technique of his profession. There are, however, many schools of law and medicine in which a college degree is not required for entrance, and some of our most eminent professional men are graduates of such schools. Engineering schools, however, have as a rule not required a preliminary college course, but have admitted young men having essentially the same preparation as those entering college, giving them an engineering degree after four years. In order that the students in engineering may be held up to the discipline of a professional school and not allowed to acquire the lax habits so common in college, the engineering school of a university has sometimes been segregated from the college of arts like the other professional schools. Some of our most successful engineering schools, too, have been from the beginning independent of any college, devoting themselves almost wholly to technical training, like the Rensselaer Polytechnic Institute, the Worcester Polytechnic Institute, the Case School, the Stevens Institute of Technology, and the Massachusetts Institute of Technology.

The fact that a preliminary college course in arts has not generally been required for a degree in engineering explains some things with reference to the status of the engineer in society. Members of the other professions, while frankly admitting that they did no serious work until they reached the professional school, nevertheless in many cases arrogate to themselves superior qualifications on account of their college course, and look down upon the engineer who has received his degree after only four years of professional study. This attitude, however, is clearly unjustifiable. It is not the college course which makes a man, but only what power, discipline, and inspiration he gets out of it. And many a man with no college course at all is far superior in every way to many college graduates. The writer has taught in an independent technical school and in a university, and he has not found that graduates from a college of arts as a rule are able to speak or write the English language more correctly, or have any better disciplined minds, or are any better informed on general topics, than the graduates of our engineering schools. Certainly, four years in college, during which time a man fritters away his time and acquires habits of indolence, injure him for future work, notwithstanding the scraps of knowledge which he may have succeeded in memorizing.

A young man who desires to fit himself for the engineering profession has obviously three courses open to him: (1) he may take a general college course first, and then enter the engineering school, just as he would the law school; (2) he may enter the engineering school of a university, or an independent engineering school, and complete his professional training in four years; or, (3) he may enter an engineering school, and take a course longer than four years, either by taking the regular four-year course first and then a post-graduate course as a candidate for a higher degree, or by arranging his work to cover more than four years and making it include such liberal studies as he may desire. The writer is acquainted with a great number of men who have pursued each of these courses, and it is not at all apparent that those who have pursued the first course have as a rule succeeded better in their profession, or attained positions of more influence in the community, than those who have pursued the others.

The first plan—that of taking first a college course in arts and following it by a professional course—is considered by many eminent authorities to be the best and the ideal arrangement. Admitting, as every one must, the importance of acquiring a thorough acquaintance and discipline in liberalizing studies, as well as in strictly professional studies, it raises the question whether it is better to take first a course in which these liberal studies are concentrated to the exclusion of technical studies, and to follow it with a course in which the latter are concentrated to the exclusion of the former, or to take one course in which both kinds of studies are carried along simultaneously. On the one hand it is urged that when pursuing professional studies the student should concentrate his attention on them, and that liberal studies would distract him. On the other hand it is urged that the pursuit of liberal studies alone will not be undertaken with seriousness and purpose, and that if such studies are to be of benefit they should not be taken and then all interest in them abandoned, but that interest in them should be carried along simultaneously with strictly professional work. Much depends, no doubt, upon the individual student. Some like change of study, and can do better work when their minds are relieved from the tension of one subject by turning to an entirely different one: while others can do better by concentrating for a long time on one kind of subject.

The strongest objection to this first plan lies in the unsatisfactory results of the usual college course in arts. Those who urge this plan are generally idealists, whose habit it is to form first in their own minds a conception of what ought to be best, and then conclude that it is best, without much regard to facts. If the usual college course produced the results that it ought to produce, this plan would perhaps be the best, for those who can afford the time. But unfortunately, the lax habits too often acquired in college, and dissatisfaction with the usual results achieved, have been admitted by some of the most eminent authorities. Senator Lodge, for instance, in his "Early Memories" says, referring to his course in college, "But in all my four years I never really studied anything, never had my mind aroused to any exertion or to anything resembling active thought until in my senior year I stumbled into the course in mediæval history, given by Henry Adams." And again he says, "so it comes to pass that I think with sorrow of my own folly and entertain serious doubts as to the perfection of that unrestricted freedom of election which gave my folly scope and opportunity."

Abraham Flexner, in his volume, "The American College," says, "Now as a matter of fact, the college does not even rise to the accepted standards of the commercial world, to whose demoralizing influence its scholarly ideals are occasionally alleged to have succumbed. For college standards of success are actually below those that prevail outside. A youth may win his degree on a showing that would in an office cost him his desk." And again, "the important thing is to realize that the American college is deficient, and unnecessarily deficient, alike in earnestness and in pedagogical intelligence; that in consequence our college students are, and for the most part, emerge, flighty, superficial, and immature, lacking as a class concentration, seriousness, and thoroughness."

President Pritchett, of the Carnegie Foundation, says, "The two objections generally brought against the college to-day are vagueness of aim and lack of intellectual stamina."

President Jacob G. Schurman, of Cornell, in one of his reports, said, "The college is without clear-cut notions of what a liberal education is and how it is to be secured, . . . and the pity of it is that this is not a local or special disability, but a prevalency affecting every college of arts in America."

Professor Charles M. Gayley, in his "Idols of Education," is very severe, as the following extracts show: "The boy enters our colleges 'a badly damaged article,' one-sidedly prepared, or not prepared at all, he goes through college accumulating courses, but not education; desperately selecting studies least foreign to his slender capacity for assimilation, or most easy to slur, or most likely to turn to superficial ends. He is by no means always lazy, nor oblivious that now is the chance of his life; but he has no core of knowledge to which the facts he fumbles may cling, no keen-edged linguistic or scientific tools with which to cut to the heart of the matter; no memory trained and enriched, no taste, no imagination, no judgment balanced by frequent trial, no habits of remorseless application. He has bluff but not confidence, he has promise but not power; the subjects of his study have not been correlated. The goal has been neither discipline nor intrinsic worth. He has probably never studied one thing thoroughly. He has not been guided; he has not been taught; he has not conquered work. He has been distracted; he has been amused."

And again, "Our graduates are characterized by lack of information, lack of grasp, lack of culture. This is no prejudiced account of the case. It is attested by our leaders at the bar, on the bench, in the pulpit and in the hospital, and by our captains of industry. Also by educated foreigners."

And again, "Save so far as a general choice between industrial or academic schooling is conceded, the pupil should encounter no elective system until he is able to enter upon the true university course which now begins with the beginning of the junior year, and even then a system so rationalized that the perils do not outweigh the privileges." . . . "The long and short of it is that we, educators, do not educate. We are fuddled with educational fads; and we fuddle the schools in turn."

Professor W. G. Sumner of Yale, said, "I never see anything more pitiable than the helpless floundering in a new subject of a young man far on in his education who has never yet learned to use his mind."

Professor Charles H. Grandgent, of Harvard, in his address entitled "The Dark Ages," says, "Students are always ready to do anything but study. Study is hard and distasteful, because our boys and girls have never been used to mental concentration. Any other activity, be it athletics or 'social service,' seems to them less painful, hence more profitable. . . . You must have noticed how very difficult it has become for college students not only to write but to read their mother tongue. We give them books to study, and the boys, for the most part, obligingly plow through them, for they are good fellows; but they are no wiser after than before. . . . It is pitiful to see the agonies that the ordinary college student has to suffer, if he is obliged to learn anything outright. It is amazing to see how readily he forgets the things which he is told, and which, for the moment, he apparently understands."

According to the above testimony, and from the writer's experience of more than thirty years, in plain English, the "thorough training" which is so often claimed, by educators, to have been obtained by college and engineering graduates, is a fallacy. A few men get it, all have the opportunity to get it, but the majority do not get it. It depends on the student. The diploma is no guarantee that he has it.

The historian, Gibbon, referring to the ignoble son of one of the best of the Roman emperors, who had given his son the best educational advantages, makes the striking remark, "But the power of instruction is seldom of much efficacy, except in those happy dispositions in which it is almost superfluous." In other words, the men who will get an education anyway will profit by schooling; others will seldom get much from it.

There is much misapprehension with regard to education and to its aims. The word "education" means, by derivation, drawing or leading out; that is, it should draw out and develop the inherent powers of the man. By many, however, it seems to be considered to mean *to put in.* The teacher is supposed to put knowledge into the mind of the student, and the student's work is often gauged by the amount which he can retain or remember. Such education is of little value.

The usual college course offers abundant examples of this. The writer believes, after many years of experience, that only a small proportion of the students taking such a course have their main interest in their work. They are there because their parents send them and pay the bills. Their main interest is in other things than their studies—in the social activities, in athletics, in the football games, in the college life, in having a good time, and so on. They have no plan and seem to be wandering about aimlessly among the courses that are offered. If, as is usually the case, they can choose their courses, they too often select the easy ones. They talk with other men who have taken these courses and if they are told that a course is easy, they will "take a chance" at it. Their object is, as a rule, not to gain discipline but to get through; to do only enough to "put it over." This is, of course, demoralizing, and such an attitude does not fit a young man for the problems of life. A friend of the writer recently said that his son, at college, had asked for an automobile, and upon being refused had complained and said that every boy in his fraternity had one. A father who gives his boy in college an automobile to play with commits a crime, and does not deserve to have a son who amounts to anything. Moreover, he is helping to demoralize many other boys who have higher aims and real desire to profit by their college course.

The aim of the college course is frequently said to be "culture." If I may define culture, I may admit that it should be the aim, but if the word means only an external smoothness and roundness of outline without regard to intrinsic qualities, it is a sham. Professor Sumner speaks of a kind of culture which he says might be called sapolio culture "because it consists of putting a high polish on plated ware." He adds, "there seems great danger lest this kind may come to be the sort aimed at by those who regard culture as the end of education." If I may define culture as a system of training which brings into intelligent activity all the best powers of the mind and of the body, which teaches how to study, and which develops in the student the power of attacking a new subject or a new problem, I would admit this sort of culture to be the aim of education; but this is discipline and not what is usually termed culture.

Professor Baynes said, "The true end of all higher education is not so much to fill the mind as to quicken and train its power, not so much to impart knowledge as to awaken thought."

All this should not be considered necessarily derogatory to the college itself. Much depends upon the particular college. In some, especially those not frequented by large numbers of sons of *wealthy parents*, the standards of accomplishment and the earnestness of the students may be high; while in others they may be low. What has been said is merely a statement of what are believed to be facts. Moreover, if these facts are as stated, the responsibility often rests more with the students and their parents than it does with the college, which really offers opportunity for discipline and training which are not embraced. Not infrequently parents send their sons to college admitting that they do so for social reasons; and the bad habits which young men frequently acquire are due largely to lack of discipline at home. It is unquestionably easier for a parent or a teacher to let a young man have his own way rather than to enforce discipline, but parents who pursue such a course are only laying up sorrow for themselves as well as for their sons. And teachers who pursue such a course are injuring their institution and their own reputation as well as their students. There is, no doubt, much that is beneficial in the "college life" that a young man gets in college. The intimate association with his fellows, the opportunities of forming lasting friendships, the insight into individual character, the atmosphere surrounding a body of young men pursuing varying aims, all tend to broaden and develop character. This is present in a less degree (and sometimes almost lacking) in the independent technical schools, and is an argument in favor of taking a college course before entering the professional engineering school. But this college life should not be the main thing, and should be subordinate to the acquisition of sound mental training and discipline. In this, as in everything, it is a question of proper balance; and too many young men in college allow the college life and the outside activities,—social, athletic, and others,—to become the main thing, to the great detriment of the mental discipline and the habits that are more important.

It is probably the realization of the laxity of the usual college course, coupled with the fact that the earliest engineering schools were modeled on the second plan, by which a college course was not required as a preliminary to the engineering course, that has led our universities and technical schools to adopt the same plan. The standards of work and the earnestness of the students are undoubtedly greater in the engineering schools than in the colleges. The danger of this second plan lies in the fact that the professional school naturally tends to make its curriculum consist strictly of professional or allied subjects. This has necessarily led to a certain narrowness in engineering graduates, and a certain habit on their part of devoting themselves purely to the technical details of their profession. This narrow course of study is, therefore, responsible, in the writer's opinion, for the narowness of many engineers which has been referred to elsewhere in this book. Up to within a short time the curricula of most of our engineering schools were almost entirely technical, though sometimes with a little instruction in English, French, German, Economics, or some other liberal studies. Of late, there has been a tendency to introduce more liberal studies into engineering curricula, but their amount is still small in most cases.

The larger the proportion of time devoted to liberal studies, the less remains for technical subjects, so that the student cannot be carried as far into professional details as he could if all the time were devoted to them, unless the latter are further specialized. Engineering schools generally offer a choice between the different branches—civil, mechanical, electrical, sanitary, mining, etc. One of these having been selected, the curriculum is generally prescribed, with no options except in minor matters. But the desire to carry students farther in professional subjects, without extending the course beyond four years, and also to permit the introduction of additional liberal studies, has led in some cases to further specialization of the courses named; for instance, allowing a student in the senior year of the civil engineering course to choose between hydraulic engineering, railroad engineering, or structural engineering. The breadth that is supposed to be given by the introduction of liberal studies like history, economics, language, etc., is thus counteracted by greater narrowness in the professional studies. The writer believes that this is a mistake, unless the professional specialization is very slight. It is much better to offer such professional specialization in post-graduate courses. The young man entering an engineering school is presumed to have decided upon a career in applied science. He has a free choice between the prescribed courses in the main branches. In most cases he finds it difficult enough to decide between civil, mechanical, or electrical engineering. Moreover, a civil engineer should have a considerable acquaintance with mechanical and with electrical engineering; otherwise he will be a narrow civil engineer, and his success will be much retarded. The converse is also true. It seems to the writer a mistake to require or allow him to specialize still farther in civil engineering, itself, in an undergraduate course. He should not be encouraged to follow the whim of the moment, at the expense of a broad knowledge of engineering in general.

This brings us to the third plan which may be followed, namely, to take first an undergraduate engineering course, and to follow with a post-graduate course in such special professional studies as may be desired. Instead of this, some urge that the undergraduate course should be extended to cover five or even six years, thus permitting the introduction of more liberal studies, and also, perhaps, of carrying the professional studies farther than they could be carried in a four-year curriculum. This last plan has been adopted by Columbia University, where the engineering courses require as a preparation, not less than three years of college work, with specified training in mathematics, physics and chemistry. The engineering courses themselves cover three years, so that the entire course is six years in length. What seems to the writer a serious objection to this plan is that the great majority of engineering students are not willing to spend more than four years in an undergraduate course. Most of them want to get to work, and they want some kind of a degree at the end of four years. If they are willing to spend six years in study, they prefer to take an undergraduate degree in four years, either in college or in an engineering school, and then return for two years more in the post-graduate school as candidates for a higher degree. The Columbia plan, therefore, it appears to the writer, will unduly restrict the number of students in the engineering school, and will correspondingly lessen the influence of the University in the great field of applied science.

All friends of education will watch the experiment at Columbia with much interest. Undoubtedly New York is the most favorable place for such an experiment, because there are several institutions there, or in the neighborhood, which offer the regular four-years' course in engineering; and with the great population within a few miles, it is well that there should be one institution offering a more extended and elaborate course. The Columbia course has further the great advantage that it is practically a prescribed course; not only in the three years in the engineering school, but also in the pre-engineering course of three years in the college. This college course of three years, however, is devoted almost entirely to mathematics, chemistry, physics and drawing. Of courses which are known as the humanities, this curriculum only includes a year and a half in English, a year in French, a year in "Modern Civilization" and a year in Economics. Counting the course in Modern Civilization as 1½ courses, this is only two courses more in the humanities than are offered in the Harvard Engineering School course of four years, and really only one course more, in view of the Harvard requirement that all candidates for the degree must have a reading knowledge of at least one modern language (and no more than Harvard if its courses in Accounting, Business Administration, and Commercial Law are considered humanities). The principal advantage of the Columbia course would, therefore, seem to be that it spreads the engineering and scientific instruction over a longer period, enabling the student to do more thorough work and to reflect more on what he learns (if he will), and perhaps also going somewhat further in some of the technical subjects than the ordinary four-years' engineering course. This ordinary four-years' course, however, if the student learns the fundamentals thoroughly, supplemented by one or two years in advanced work, and including a course or two in some general subject, would seem to give all the advantages that can be claimed for the Columbia course.

The first class graduating at Columbia under the new plan was the class of 1918, and the total number of students in all courses has shown a falling off from 489 in 1914-15 to 185 in 1920-21. Columbia gives the B.A. degree to students who have taken the college preparatory course after they have completed the first year of the engineering program, and the engineering degree upon completion of the full engineering program.

A similar plan has been followed since 1893 at the Thayer School of Engineering at Dartmouth College, where, after three years in college studying certain specified subjects, a student may enter the engineering school, receive the B. A. degree after one year; then, after about five months' engineering practice, he may return for the second year in the engineering school; that is to say, the fifth year of the course, when he receives the degree of civil engineer. At this school the maximum enrollment was in 1907-08, when there were 40 students. In 1920-21 there were 9 students in the engineering school and 1,888 students in Dartmouth College.

Considering these figures, it must, of course, be borne in mind that the war has seriously deranged the engineering schools, and that they are only just coming back to a normal condition. It is also to be remembered that there is much to be said in favor of a small school of engineering, because in such a school the student can receive more individual attention from the Professors, and is not turned so much into the hands of inexperienced assistants.

The first plan, by which the engineering school is strictly a post-graduate school, requiring a college course of four years as preparation, will also, in the present state of development, unduly restrict the number of students and lessen the influence of the University in the field of applied science. This plan was first tried at Harvard University from 1908-1914. After 1906 no new undergraduate students were admitted to the Lawrence Scientific School, which was the undergraduate engineering school of Harvard University up to that time, but was then abolished and superseded by the graduate school. In 1905-06 the number of students in the Lawrence Scientific School was 504. As a graduate school, the engineering school never had more than 152 students, which was the number in 1913-14, when an agreement was made to combine the engineering work with that of the Massachusetts Institute of Technology. This agreement was declared illegal by the Supreme Court, and Harvard University then made its engineering school an undergraduate school with a course of four years for the Bachelor's Degree in Engineering and with advanced courses of one or two years for students who desire them, leading to advanced degrees. The number of students in 1920-21 in this school was 233, and in 1921-22 it is apparently 258. As a graduate school, the maximum number of graduates was 24 in 1914.

It appears, therefore, as a result of this discussion, that the engineering school should offer an undergraduate course of four years, with an opportunity of selection between the main branches of engineering; and also, if its circumstances allow, post-graduate courses leading to advanced degrees after one or two years. The character of the undergraduate course should be carefully considered, and it should not be narrow, either by excluding all liberal studies, or by specializing in professional subjects. Perhaps the fundamental facts on which it should be based may be formulated as follows:

1. While the intrinsic differences between men must be recognized in any scheme of education, engineering students have decided that they wish to pursue, and presumably are fitted for, applied science.

2. Few of them, however, before studying engineering, can correctly judge in which branch of engineering their main interest or ability lies, or in which fate will cast their careers.
3. None of them can correctly judge what curriculum is best fitted to prepare them for an engineering career.

The curriculum should not be entirely technical, but should include at least the opportunity to take some liberal studies. In Harvard University, therefore, the students are offered the choice between nine curricula, each in one of the branches of engineering. In each of these the studies are prescribed, except for a few nonprofessional options. The curricula in civil, mechanical, and electrical engineering are identical up to the senior year. If, therefore, a student takes the course in civil engineering, and finds himself later called upon to engage in mechanical or electrical engineering, he will be able to do so, for he will have received instruction in the fundamental principles of all. The purely technical studies are not carried so far, in the undergraduate courses, as in some schools where there is more specialization; but post-graduate courses are offered, leading to the Master's or Doctor's degree, in which they may be pursued to any desired extent. In the first two years there are three required or elective studies in liberal subjects. The Harvard College course requires for the bachelor's degree seventeen full courses of a year. At least six of the courses offered in college are included as required courses in the engineering programs, leaving eleven college courses not specifically offered in the engineering school; but two of these may be taken by the engineering student as the electives of the first two years. It may therefore be said that at least eight-seventeenths of the engineering program consists of studies optional with college students, but required in the engineering curricula, which may, therefore, be considered to be about one-half strictly technical. By this plan it is believed that the charge of narrowness, in any sense, cannot be made; while at the same time the fundamentals of engineering are taught in the undergraduate course, quite far enough to serve as a preparation for practice; and in the graduate school a student may go as much farther as he likes.

In its small degree of specialization, this Harvard course is believed to differ from any other, and the writer thoroughly approves of it.

Some engineers and educators no doubt believe that an engineering course following a college course is the ideal plan for those who can afford the time. This may be true in certain cases, depending upon the student, the parent, and the college. If the student can get the most out of a college course, and avoid the temptations to take the easiest way, it may be the best for him. There is no reason, however, why such a man could not follow the Harvard plan, extending his undergraduate engineering course to any desired length, but of course he would then receive only one degree. Some men are degree chasers, and seem to think that their success is made if they can attain the right to affix some letters to their names. This, however, does not seem a very worthy ambition; it is only what the letters stand for that makes them of value, and sometimes they stand for little—to those who know. "God will not look you over for medals, degrees, or diplomas, but for scars."

A young man who decides to follow the first plan should arrange his college course with great care, so as to facilitate his subsequent professional work as much as possible, and avoid gaps between professional subjects and the preparatory subjects on which they depend. The facility of students to forget what they have been taught is one of the wonders of education. The writer knows men who after four years in college required four more years to complete an undergraduate engineering course. They had devoted themselves entirely to "culture" in college.

With reference to the temptations to desultory work in college, it is a matter of surprise that if the criticisms of high authorities are valid, nothing is done to remedy the situation. The fundamental trouble seems to be the great freedom that the student has in the choice of studies, combined with laxity of discipline and low standards of accomplishment. The elective system had its origin in the perception of the fundamental truth that men are not equal, and that all should not be put through the same mill. To require the same program of every man is obviously wrong. But in correcting this by the unrestricted, or almost unrestricted, elective system, greater wrongs were introduced. It is always so with reforms. There are many men who, when they perceive a wrong, think they must at once set out to correct it. They see the wrong clearly, and they see—or think they see—a way of correcting it; but their minds are so fixed on the particular wrong that they seek to correct, that they do not follow out the consequences of the remedy they propose, and so frequently, while correcting one wrong, they create a worse. Our legislation is full of such instances. Of course this does not mean that wrongs should never be corrected, but it does mean that a reform should be introduced slowly, only after a careful study of the proposed remedy and its consequences, and by practical men rather than by theorists and idealists.

We have seen that Professor Gayley thinks there should be no electives in college below the junior year, and few afterward. Professor A. G. Keller, of Yale, argues very strongly, and to the writer's mind very convincingly,* in favor of a required course in college covering about three-quarters of the required work, leaving one-quarter for electives. The writer has never been able to undestand why the colleges have not imitated the programs of the technical schools, which have been entirely successful, and are admittedly free from most of the criticisms that have been directed against the college course. While it is not always, or perhaps often, possible to tell what career is the correct one for

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* "The B.A. Degree in America," by Professor A. G. Keller, *Scientific Monthly,* February, 1918.

a boy entering college, yet it should be possible, if parents and teachers would give attention to it, to tell what *general line of work* he is fitted for; whether for applied science, for the law, for business, for literature, etc. The college might then offer to students a choice between a number of courses, one leading to applied science, one to pure science, one to the law, one to medicine, one to divinity, one to literature, one to business, etc. Each of these courses should offer a program of studies largely prescribed, laid down by those who know what course of training is best fitted to equip a man for the general line chosen, with a relatively small proportion of the time open for the choice of electives. This is exactly what the engineering schools have been doing, and doing successfully; and it may be doubted if there is a college in the country which has an engineering school and a college of liberal arts, in which the engineering school—if it has been adequately supported, and encouraged equally with the college of liberal arts—has not outstripped the latter in number of students and in influence; although the students in the college of liberal arts, with their customary self-conceit, sometimes look down on the engineering students as "utilitarians," or as lacking in "culture," because they are learning something that they can make practical use of. Such a plan as suggested, if accompanied by discipline—which, by the way, is always easier to enforce in a technical school than in a college, because the results are tangible—and by greater discrimination in the selection of teachers, would in the writer's opinion go far to meet the criticisms so often leveled at the college.*

There is and has long been a great neglect of natural science in our colleges. A young man or woman may graduate from almost any one of them with scarcely any accurate knowledge of the phenomena of the natural world in which we live. On the other hand, there is a great exaggeration of the so-called human element. Young, immature students crowd into the courses in economic and social subjects, and in many instances the importance of these subjects is exaggerated by the college authorities. Formerly, it was thought that a college president must be a minister. That belief, happily, has passed, but even now, if a minister is not selected, the president is generally an "educator," a psychologist, an economist—rarely a scientist, a lawyer, a business man, or an engineer.†

These economic and social studies are no doubt interesting and valuable, but the young men who study them have no background of experience on which to base their conclusions. The subjects themselves are uncertain. The professor at one college may differ dia-

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* See the books referred to previously. The reader who, like the present writer, is inclined to smile at much of the modern pedagogical writing, will also derive much amusement from "A Joysome History of Education," by Welland Hendrick, published by *The Point of View,* Nyack, N. Y.

† Probably every reader has heard the epigram: "Those who can, do; those who cannot, teach." To which a college professor has wittily added the following: "and those who can do neither are made college presidents." Happily most cases are exceptions.

metrically from the professor at another. There are all sorts of opinions, and few of them can be submitted to scientific demonstration. The inevitable result is that many students, especially those who are conceited and lacking in balance, are led to conclude that, where doctors disagree, one opinion is as good as another, and their own opinion as good as anybody's.

Under the attractive guise of liberality, tolerance, broad-mindedness, and looking at all sides of a question, our young men and women are exposed, or expose themselves, to the teachings or writings of many who are merely unbalanced or crazy fanatics. It is as though they should deliberately expose themselves to the smallpox, in order to show liberality of mind and a desire to see all sides of a question. Nobody should expose himself to a contagious disease, trusting to his powers of resistance to avoid infection, unless he is obliged to do so; nor should one voluntarily expose himself to social disease germs. There are social as well as biological germs of disease, which lurk in the social body, and which, in a favorable environment, will develop and spread with great rapidity and with dire results. These social germs of disease are *ideas*, not things. One favorable environment for germs of social disease is found in the minds of well-meaning but inexperienced and idealistic young men and women. These facts form the basis for the charge which is frequently made, and which is unfortunately truer than it should be, that our men's and women's colleges (not engineering schools) are nurseries of socialism.* The well-meaning but often idle rich and college-educated people, who wish to appear progressive, broad-minded, and tolerant, are also open to this charge. A United States judge recently publicly said in Boston that the spread of socialism and bolshevism was largely due to the parlor Bolsheviks and the Harvard Liberal Club. It would be much better for our young men and women if, instead of studying these economic and social subjects so intensively in college, they should take but one course in economics which would show them the scope and methods of the subject, which should be taught by a thoroughly well-balanced man; and if they should study mainly science, mathematics, history, logic, and the classics, learning to think straight and to know the deeds and lives of great men; leaving for a later time the further study of economics and social subjects, when they would have some practical experience of life to guide them. A very distinguished man not long ago told the writer that when he graduated from college he had a large and varied assortment of economic knowledge; but about two years' experience in business showed him that it was mostly wrong. Abstract knowledge is of little value, except in the sciences which are themselves purely abstract, namely, mathematics and logic. Even these must be used merely as tools if they are to be of practical service. In other sub-

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* See an article by Vice-President Calvin Coolidge in *The Delineator* for June, 1921, on "Enemies of the Republic."

jects a man cannot learn anything thoroughly unless he can relate it to his experience.

For these reasons the writer has long believed that an engineering training is the best preparation for any walk of life, and that if a college course is taken it should be mainly devoted to science, the classics, history, logic and mathematics.

In the pursuit of ideals it not infrequently happens that to remedy Evil A will necessarily produce an Evil B; that to remedy Evil B will produce Evil C; and that to remedy Evil C will produce Evil A. There may even be only two horns to the dilemma; it may be that Evil A may be remedied only by producing Evil B, and that Evil B may be remedied only by producing Evil A. In these cases a choice must be made of what will be best on the whole. It is a question of balance. Even if an evil exists it does not follow that it should be remedied; it may be that it cannot be remedied without producing something worse, and that the best balance has already been struck. It seems to be so in education. Evil A may be non-recognition of the differences in individuals; this was the evil in the old prescribed course, the same for every student. Evil B may be the lack of discipline; this is the evil in the unrestricted elective system. It is a question of balance, and the curriculum which will best balance these evils will be the best curriculum. The writer believes that the best balance will be by a course almost entirely prescribed, but allowing the student to choose between a number of such courses.

It must never be forgotten, however, that more depends upon *how* a subject is taught than upon the subject itself, and that the greatest discipline may come from a subject supposed the least capable of it, if it has the right teacher. In Europe, students used to move from one university to another, in order to study certain subjects with certain leading men. This has seldom been done in this country, and cannot well be done, except in graduate work, owing to differences in the curricula. It might be an improvement if it could be done more.

The education of the engineer is never finished. He must be a student all his life, like the physician or lawyer. The fundamental bases of mathematics and science are of course immutable, but the applications change rapidly. The methods of purifying drinking water, of treating and disposing of sewage, have been revolutionized within comparatively few years. The automobile, the aeroplane, the steam turbine, are all recent inventions. A new form of road surface has come into use within a few years. New properties of materials, new methods of treatment, and new materials themselves, are being discovered. New experiments in hydraulics are leading to modifications of old methods and formulæ. New forms of construction are being introduced. Applied science is in a constant state of flux. It is most important, therefore, that the engineering student should learn *How to Study.* The college graduate who cannot by himself pursue farther a subject that he has begun, or take up an entirely new subject and master it alone, has largely failed in his education. It is not necessary to teach everything in college. Yet strangely enough, little attention is given to training students how to study. It seems to be assumed that because they study, they know how to study. It might as well be assumed that because they can sing, they know how to sing correctly. The consequence is that whenever any subject of any human interest presents itself, educational theorists think it should be taught in the schools. They seem to go on the theory that nothing can be learned that is not taught in school; and our college and preparatory school programs are crowded with subjects that are no doubt of interest and importance, but that had better be left for the student to study by himself, confining the school work—limited in time as it is—to the teaching of fundamentals, to giving the student mental discipline, high aims, mental vision and perspective, mental courage, and the power to study by himself.*

It is not necessary to give here a complete discussion of what a curriculum in Civil Engineering should comprise. Nevertheless, for the benefit of any young men who may read this book, especially those who may contemplate taking a college course preparatory to a professional course, a few remarks may be desirable.

The civil engineer must have a thorough training in several branches of natural science. It is sometimes said that civil engineering is a three-legged stool rest-

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* See the writer's pamphlet, "How to Study," published by McGraw-Hill Book Co., 1917.

ing upon a knowledge of chemistry, physics, and mathematics. These, indeed, are fundamental, but other things, especially mechanics, are equally necessary. The civil engineering curriculum should comprise a course of at least one year in chemistry, of at least one year and preferably two in physics, both chemistry and physics including laboratory work, two years of mathematics extending through the calculus, and at least one year in mechanics. A student preparing for civil engineering should also acquire a reading knowledge of French and German, and it may be to his advantage to acquire some knowledge of Italian and Spanish. He should have a course of at least one year in history, at least one year in English, one year in economics, and it will be greatly to his advantage if he can gain some knowledge of accounting. As the civil engineer deals with topographical features of the earth's surface and with stones, cement, and other materials, he should have a good knowledge of geology. The work of the surveyor, also, requires for some of its operations a knowledge of astronomy. All of the above subjects can, as a rule, be covered in a college course, and they should be covered by the college student who intends to take an engineering course later, and who desires to economize time in his later professional studies. Moreover, a knowledge of mechanical drawing is necessary for the engineer, which is usually given in the freshman year of engineering courses and is necessary for the proper understanding of the professional courses which follow. The college student should, if possible, either in college or outside, obtain the equivalent of such a course in drawing. Descriptive geometry is a very important study for the engineer, but it is difficult for most students, and with the modern tendency towards making everything easy and shunning everything which is difficult the courses in descriptive geometry, even in the engineering schools, have in the last few decades, in the writer's opinion, been largely weakened or emasculated. It may be difficult to get a good course in this subject in college, but it should be done if possible. To this list may be added the subject of mechanism and the general subject of power development. Some colleges offer opportunity for courses in these subjects which should be embraced by students contemplating a career in any branch of engineering.

If the college student can cover in his four years' course in college the subjects above enumerated, he will still have time to include a goodly number of other courses from among those offered by the college, which will round out his general education and at the same time help him in his profession, and upon the completion of such a course he will as a rule be able to obtain an undergraduate engineering degree in two years in an engineering school.

The curriculum of the technical engineering studies need not be described in detail. The curricula of the different engineering schools are very much alike—on paper. They may differ greatly, however, in thoroughness, in the manner in which the courses are given, and in the attention which can be given to the individual student, the latter depending upon the size of classes and the number of instructors. The technical subjects in a civil engineering course should cover those outlined in Chapter III of this book, beginning with surveying, which is now frequently given as a continuous course for about two months during the summer. The college student will do well, and will save some time, if he will take such a course while in college, and he can easily arrange to do so by attending during a summer one of the engineering summer schools, provided he has the proper preparation in mathematics and drawing.

Following surveying, the engineering curriculum includes a study of railroads in the different branches, of highway engineering, a comprehensive course in hydraulics, courses in the different branches of hydraulic engineering, and a course in structural engineering extending as a rule through two years; these courses being combined with laboratory work to a sufficient extent to enable the student to appreciate the theoretical and technical principles which he is taught in the class room.

The sanitary engineer should follow his study of chemistry with a study of bacteriology, biology, the chemistry of waters, and the chemical principles governing the purification of water and the disposal of sewage. He should also have instruction in public hygiene and in physiology.

Whether it is best for a young man contemplating the career of a civil engineer to take a college course first or to enter the engineering school at once will depend largely upon the individual and upon the college. The atmosphere and the incentives to work vary in different colleges, and of course individuals differ greatly, as well as the influences that they are under at home. The writer believes that most college students are desirous of doing hard work, and regret the distractions and the laxity which prevail so often in college. Some of them would like to be rescued from these distractions and encouraged to do more serious work, but the atmosphere of the college and perhaps the influence of their teachers is in some cases against it. If a large number of students in a college come from families of small or moderate means, and especially if many of these students are paying their own way, they will be apt to be more earnest and more desirous of doing hard work than if they come from wealthy families, whose sons are too often sent to college for social reasons, to have a good time, and to belong to a high-class social club. The writer believes that if one of our colleges should successfully remove the charges so often brought against the college course, whether in the way suggested in this chapter or in some better way, it would meet with immediate and great success, and with approval on the part of the students themselves, or at least of the better class of students; and to the young man who contemplates taking a college course before entering the engineering school, he would offer the advice to choose his college with the greatest discrimination.

To the great majority of young men who wish to follow a career in engineering, my advice would be this: Enter an engineering school as soon as you are prepared, and get the habit of *work* at once:—and not only the habit of work, but train yourself to work *effectively*. Hard work will not help you much if it is ineffective and does not lead to results. Perseverance is not a virtue if misdirected toward unworthy aims, or toward impossible aims, no matter how good in the abstract.

Broaden yourself as much as possible. Acquaint yourself with the great men who have gone before; learn what they did and said and thought, and relate all this to your own experience and aims. Read the classics in the best translations you can find. Learn to use the English language well and to speak in public without embarrassment. Extend your technical education over more than four years if you can do so profitably, but not too long, for too much school education is as bad as too little, and probably worse. Your real education will come later anyway.

To young men who enter college with no definite aim, my advice would be: No matter what career you may decide to follow, study the sciences upon which engineering is based, and as much of engineering as you can consistently get in your college course. These things will be useful to you in any career—more useful than many so-called cultural subjects. Select courses that will call forth your most serious effort, not those that are easy for you. Do not *aim* for culture, whatever you may understand that to mean, but for training.

Acquaint yourself with the principal fields of human thought, and learn thoroughly the fundamental principles of those you select. Do not go too deeply into any one, but study the fundamentals thoroughly. You cannot become a specialist or an expert in four years. If you try to become an expert in college you will more likely turn out a sham or a narrow bigot. If you *aim* for culture, you will be likely to turn out a conceited ass; if you *aim* for wisdom, you will be likely to turn out a pedant. If you work hard, take advantage of your opportunities, follow good advice, culture and wisdom will come of themselves in due time, if they are meant for you. Select as your guides men who are broad-minded and tolerant of differing opinions in controversial subjects, rather than those who are dogmatic and mentally arrogant. Give little time to controversial subjects in which your teacher may hold views very different from those held by equally good authorities elsewhere, and in which your own view—whether based on prejudice or not—cannot be proved either right or wrong; but rather study subjects in which, while there is room for independent thought, if you are wrong you can be shown to be wrong, and the reasons stated. Train your mind to be a reliable logical instrument, which you can turn upon any subject and be sure of reasoning correctly, leaving controversial subjects for later study, when you will have experience to give you the data. Learn to have respect for those who have not had the opportunity for a college education, and realize that many such men are making more of themselves than you will ever make of yourself. Above all, learn intellectual modesty even while sure of your ground, and remember that when you graduate your education will have been only begun.

CHAPTER V

CHARACTERISTICS OF CIVIL ENGINEERING AS A PROFESSION

Every profession or occupation has features which might be termed unfavorable, and others which might be termed favorable; yet what one person might consider favorable, another might think unfavorable. It is a question of personal adaptation. If a young man is distinctly adapted for a certain profession, it may have no disadvantages for him. But few young men are distinctly fitted for but one occupation. Most men would succeed equally well in any one of a number, if their training and discipline were directed toward the one chosen. Every occupation has *characteristics*, and, therefore, instead of having one chapter on the advantages of Civil Engineering as a profession, and another on its disadvantages, the present chapter will discuss the Characteristics of Civil Engineering as a Profession. Each reader may then decide which are to him advantages and which disadvantages.

First among the attractions of Civil Engineering may be placed the opportunity that it offers of doing constructive and enduring work. If, as has been claimed in this book, engineering in its broadest sense is the main element in advancing civilization, it is obvious that the engineer who builds a railroad, furnishes a city with water, develops by irrigation a tract of land previously useless, constructs a port or a canal for handling the commerce of the world, or completes or aids in completing any other large and useful engineering work, is a direct agent in doing good to his fellow-men. The engineer can look upon his completed work with pride and satisfaction, and can see before his eyes the fruits of his labor. His work is a permanent monument to his skill and diligence; it does not disappear as soon as it is done and paid for.

It is, of course, too often true that the credit for the engineer's work is given to others; but this is not confined to engineering. Ask who built any of our transcontinental railway lines, and the reply will probably give the name of some financier or promoter who carried the project to completion, and not that of the engineer who designed or superintended the work. That, however, is merely an illustration of the fact that justice is not always done in this world. And often, too, the real credit may be due to the promoter, who had the vision, the command of capital, the energy, and the perseverance to push the project. But these faculties are not beyond the command of the trained engineer, who should not confine himself to mere technical details, but should cultivate other qualities if he would make the most of himself. And it is certainly true that the financier who endeavors to carry out engineering undertakings without the advice and judgment of a trained engineer to guide him, is apt to make costly failures rather than successes, as the history of such projects clearly shows.

The second attraction of engineering is that it tends to train and develop character. The true engineer is a scientific man, and should be imbued with the true scientific spirit. He deals with the applications of the immutable laws of nature. He cannot violate those laws without the inevitable penalty being visited on somebody. His work develops the habit of seeking only the truth. He is not concerned to make the worse appear the better reason. The engineer, as a rule, does not deal in bluff; he has nothing to "put over;" though there are no doubt bluffers and charlatans in the profession.

Engineering is impersonal, dealing, as it does, with the laws of nature. Of the four learned professions, law, medicine, theology, and applied science or engineering, it has been remarked that all except the last are mainly concerned with the sorrows, sufferings, and quarrels of mankind. This may be considered, from one point of view, an advantage of the first three: for surely it is a privilege to be able to relieve suffering, to alleviate sorrow, and to compose fairly the quarrels of mankind. But the habitual contact with and contemplation of suffering, sorrow, and contention, while it may develop feelings of gentleness, kindness, sympathy, or justice, may sometimes lead to a certain callousness and indifference, and even to hardness, coldness, and lack of sympathy. However this may be, engineering is impersonal. But the laws of nature can only be applied through human agency, and the engineer must study men and learn to deal with and direct their efforts, without being concerned professionally in their sorrows, sufferings, or quarrels.

Speaking to a group of young consular appointees the other day Secretary Hughes said: "I confess that in my experience with young men the capacity I have found least often is the capacity for accuracy." Engineering trains the habit of accuracy. The engineer deals with measurable quantities, and his conclusions are often or generally based upon careful calculations, comparisons, and studies. The applications of science are superior to pure mathematics in this respect, because, while mathematics is accurate, its results depend entirely upon the data introduced into the problem. With these the pure mathematician has nothing to do; he deals with a machine which takes those data and produces a result. But the engineer is first of all, and often mainly, concerned with the data; and having decided upon them he uses the mathematical machine with a conscious realization of the relation between data and result. Mathematics is but one of the tools he uses; the others are judgment, experience, observation, knowledge of the properties of materials, and so on.

Engineering also trains habits of logical thought, though perhaps the law may be superior and other vocations equal in this respect. Engineering has the advantage over many other subjects that, while it offers ample opportunity for the use of judgment, and while many things in it may be largely matters of opinion, it deals mainly with matters in which some degree of demonstration is possible. To deal entirely with matters that are certain, as we do in mathematics (the data being assumed) does not necessarily develop the power of logical thinking, but more often merely the skillful use of the machine. Neither does the study of subjects which are much involved in doubt, in which authorities differ widely, and in which experiment and demonstration are difficult or impossible. Such are certain parts of economic theory, and such, largely, is history. Facts may be difficult or impossible of attainment in these subjects; and experiment, in the scientific sense, in which one element only is varied, is impossible. You cannot experiment scientifically in economics or history. You may put on a high tariff; but the sequence of events will not prove the effect of that tariff, because other elements are never the same. But the engineer who wishes to study the effect of carbon on the tensile strength of steel has only to prepare a series of samples alike in everything except the carbon content, and the resulting differences in tensile strength will be necessarily due to the carbon. It is true that it may be difficult to get the samples identical in all other respects; and it is also true that very slight differences in another element, such as nickel, may produce large differences in the results obtained. Before the discovery of the relations between bacillæ and disease, two samples of water might have been as nearly identical as the minutest chemical analysis could disclose, and yet one might have been the cause of typhoid fever, and the other not. In this case a microscopic organism, before undiscovered, made all the difference in the world. But these instances only illustrate the difficulty of attaining absolute certainty, and do not at all invalidate the conclusion that the power of logical thinking is best developed by the study of subjects, like engineering, in which crucial experiments are possible, in which reasonable certainty may be attained, and yet in which there is enough opportunity for the use of judgment and for differences of opinion to encourage the use of the imagination and the use of hypothesis and verification.

By its combination of the practical and the scientific, of business, administration, and the direction of men, engineering may serve to develop a breadth of view which is of great benefit. Many engineers, however, devote themselves so closely to technical details that they lose this advantage; but that is the fault of the individual, and not of the profession as such.

For reasons already referred to, the practice of engineering develops, or tends to develop, mental courage, resource and decision. No two engineering problems are exactly alike. Conditions differ, and contingencies arise which call for not only technical knowledge, but for quick decision, fertility of resource, initiative, and courage. Not infrequently something has to be done that was never done before by that engineer, or, so far as he knows, by any engineer. These are valuable qualities in any walk of life.

Engineering also develops a sense of responsibility, perhaps to a greater degree than most occupations. The writer recalls hearing the late Joseph H. Choate wittily refer to the difference in this respect between engineering, medicine, and the law, somewhat as follows: If a doctor loses his patient, it is never his fault. He can always ascribe it to disobedience of his orders or to the incurability of the case. He goes on—he lives on—and acquires new patients and new fame. If the lawyer loses his case, it is never his fault. He can always ascribe it to the prejudice of the jury, the perverseness of witnesses, or the unfairness of the judge. He goes on, and acquires new clients and new fame. But if the engineer's structure collapses, he had better be under it. He is held responsible, and his reputation may be ruined. This has not infrequently been illustrated. The collapse of the Ashtabula bridge, in Ohio, in 1876, led to the loss of some reputations and to one suicide. The collapse of the first Quebec bridge caused the loss of some reputations, including that of the principal engineer, who had been considered the leading bridge engineer in this country. He had expected that this structure would be his greatest work, and the fitting culmination of his creditable career; but instead it filled his closing years with sorrow. All this may be considered an objection to the profession of engineering, rather than an advantage. And yet a man who shirks responsibility lacks courage, and to cultivate a sense of responsibility goes far to make a strong man. Every act has its result. An unwise or ignorant or careless act may bring disaster, whether in engineering, finance, or administration. One great difficulty of our present social system is that the results of unwise acts of one man are visited on innocent people who have not deserved the penalty. If all penalties could be visited upon those who have incurred or deserved them, it would be a great improvement, but it is impossible.

One of the greatest attractions of an engineering training is the advantages that it gives, and the opportunities that it affords, in the various lines of business. We live in an age of engineering, of power, of applied science. Not a day passes that does not bring a man in contact with some phase of applied science. Wars are decided now by engineers, not by knights in single combat. Every industry depends upon the engineer. Therefore, a training in applied science, if not narrow, but combined with training in language, history, economics, and other things essential to the cultivated man, cannot fail to be of great value. The executives of many of our great corporations began as engineers. Indeed, the writer has had in his classes men who have afterward been led into very different occupations; men who have become lawyers, doctors, artists, and even clergymen; and he has never met one who has not expressed himself as greatly indebted to his engineering training. All have said that they would not willingly relinquish what it did for them. Of course, in regard to ultimate success, all depends upon the individual. A man who wills to succeed cannot be kept under. But there is no question in the writer's mind that a proper engineering training is one of the surest roads leading to a successful and useful life.

Coming to more material considerations, an engineering career is a healthful one. Some engineering work is confining, and does not require out-door exercise; but most engineering work, particularly in civil engineering, requires a good deal of out-door work. Sometimes, indeed, it requires more than is pleasant, and calls for exposure, risk, and danger in severe weather. Generally speaking, however, it may be said with truth that civil engineering is a healthful and physically stimulating occupation.

Much of what has been said applies to other branches of engineering, and not alone to civil engineering; but no distinction between the different branches of the profession has been deemed necessary or desirable.

Engineers, and more particularly their wives, often complain that their work takes them about the country so much that they are unable to settle down and have a home in one place. A civil engineer may be engaged for some years on a piece of work in Massachusetts, but his next job may be in the far west, or even in a foreign country. This may be true whether he is working for himself or for an employer or corporation. Even if a civil engineer has a fixed position on a railroad, his work may be liable at any moment, as in an emergency, to call him away for days or weeks to distant parts of the company's system, if it is a large one. He cannot count, as most business men can, upon spending every night at home with his family; and he may be obliged, at short notice, to change his place of residence.

While the above criticism undoubtedly has force, yet it may be questioned whether the civil engineer necessarily has to lead a more nomadic life than most men in other occupations. A salesman for a commercial house may have to be on the road, away from home, practically all the time; and even a high officer in a business concern often finds it necessary to change his place of residence, if the business of the concern is not concentrated in one place. A minister often has to move. Methodist ministers used to do so every year. The officer of the army or navy is notoriously nomadic and never knows to what post he may be ordered. Railroad officers frequently go from one road to another, and move their places of residence. The business of a lawyer, also, often requires extended absences from home, if not a change of domicile. The engineer, too, may, if he wishes to practice in one place, open an office there, like a doctor or lawyer, and go away as little as he may choose.

Generally speaking, however, it may be admitted that the business of engineering is so spread out over the earth's surface, and work in one locality is so often done by or under the direction of engineers whose principal place of business is in an entirely different locality, that the civil engineer is less able to establish a home in one place and count upon occupying it permanently and continuously, than men in most other occupations. By some this will be considered an objection, by others an advantage. If a man is very domestic in his tastes, has little love for travel or adventure, and is unhappy unless he can spend his evenings regularly by his own fireside and in the same house, he would probably not select the career of an active civil engineer. Some, however, will consider the necessity of more or less change of location as an advantage. Certainly it makes a man acquainted with different parts of the country, enlarges his acquaintance, teaches him that there are fine people anywhere, acquaints him with different points of view, and so necessarily broadens him, makes him tolerant, and prevents him from falling into a narrow rut and becoming prejudiced and provincial.

Moreover, if an engineer desires, he may attach himself to some branch of the profession, or to some concern, where there will be the minimum chance of moving about. Many civil engineers have lived their whole lives in one place. Nevertheless, as already stated, the likelihood of a change of location, and the necessity of absence from home for periods more or less long, are probabilities or possibilities that the prospective engineer must face.

Another objection sometimes urged against civil engineering is the fact that the work of the engineer is often done out of doors, under severe conditions of weather and exposure, and sometimes at considerable risk of accident. It is true that works of construction must be done out of doors, and that some engineering work, like railroad location and construction, hydraulic works of some kinds, especially if in remote or inaccessible regions, tunnel work, some kinds of foundation work, coast works, and other works, may involve the necessity of severe exposure, and some risk of injury or accident, or even of life. This is not true, however, of all kinds of civil engineering-work. Some kinds require work in the office only, and give too little out-door exercise. The young engineer, while gaining his experience and making a place and reputation for himself, should expect and desire to do location and construction work in the field, for in that way he will best gain the practical knowledge of materials, their handling and use, and the control of men, which will be necessary for his success in higher positions. To gain this necessary experience should not require many years, and afterwards he may be able to avoid serious exposure or risk if he desires. In this case, however, as in the case previously discussed, there are advantages. Exposure and hardship, and even strenuous work out of doors, develops stamina, courage, and health, and will not be shunned by the strong, ambitious man who is otherwise fitted for an engineering career. It may, however, perhaps fairly be said that civil engineering in general is not a favorable occupation for a young man who is physically weak. Perhaps this would be better expressed by saying that such a man, if otherwise fitted for the profession, should direct himself along professional lines that will not require severe physical exertion; and this can easily be done. Such a man, for example, should aim to secure work, not in connection with new construction, but in conection with the management of completed enterprises. As already stated, much of the highest kind of civil engineering work, as, for instance, structural designing, calls for little or no out-door exposure, and scarcely any risk of physical injury.

Another objection sometimes urged against civil engineering is that the demand for engineers is very variable, being very great in times of prosperity, when much construction is being done, while in times of business depression many engineers are unemployed. This is true, but it is not confined to engineering, though that profession is perhaps more subject to variation in demand than some others. Medicine is probably the most naturally stable of the professions; that is, the least subject to fluctuations due to business depression or prosperity. People will always be subject to sickness, and perhaps when business men are worried by hard times there is more likelihood of sickness than in times of prosperity, when everybody is optimistic. Ministers, too, do not lose their positions in times of depression, for at such times people most need encouragement, faith, and hope. And probably there is as much quarreling, and as many law suits, at one time as at another, though with less business there will generally be less legal business to be done. There is, therefore, little doubt that civil engineering is open in some degree to the objection just referred to.

Reference has been made to the fact that civil engineering does not, as a rule, deal with sentiment. It is concerned with cold facts, while with the doctor and lawyer, sentiment enters largely into the feelings of their clients. For this reason, the doctor and lawyer can charge larger fees than the engineer, even though their services may be of less real value. When a man thinks he is going to die, he may be very glad to pay his physician or surgeon a large fee if he can be made to believe that this practitioner has saved his life. In reality, the medicine given him may have been bread pills, or the operation may have been unnecessary. It is a matter of sentiment. So if a man is sued for a large sum, gets frightened nearly to death, and his lawyer gets him out of his scrape, he may be delighted to pay the lawyer a good part of what he stood to lose or thought he stood to lose.

There are of course many noble physicians who obtain their main satisfaction from the consciousness that they are relieving human suffering and bringing comfort and cure to the afflicted, with little thought of their own personal profit—or with no more than a due regard for such profit; I say with no more than a *due* regard for such profit, because a due regard for one's personal interest in any walk of life, if combined with the strictest regard for the rights of others, is a fundamental moral duty.

"Self love, my liege, is not so vile a sin
As self-neglecting."

We all know such physicians. The "grateful patient" is a pleasant and cheering accompaniment of medical practice of the highest kind.

There are also many lawyers who practice their profession in a similar spirit and strive to compose quarrels rather than to prolong them. Nevertheless, there are physicians and lawyers who are quick to take advantage of the opportunity of making use of sentiment in fixing their charges, and some have used it in a way contrary to what seems to the writer sound economic principles. Some physicians delude themselves into thinking that they are charitable because they treat poor people free; but charity implies self-denial, and if a doctor who treats poor people free makes up for it by charging higher prices to his wealthy patients, he is not practicing charity at all, but is a socialist and is merely making his wealthy patients pay the bills of poor patients by hiring him to treat them for nothing. Some surgeons have the practice of charging for an operation a certain percentage of the income of the patient, and they criticize severely such a principle as that laid down recently by the Johns Hopkins University, by which the maximum charge for an operation is fixed. But it is obvious that if a very wealthy man is forced to pay five per cent. of his income for a simple operation, while a man with little or no income pays nothing, the doctor is not benevolent, but is simply forcing the rich man to pay the bills of the poor man, without any regard to the question whether the poor man's poverty has been the result of extravagance, intemperance, or lack of thrift. Such a practice penalizes thrift and saving, and encourages the opposite qualities. There is no more reason why the rich man should be forced to pay the doctor's bills for a poor man than there is for forcing him to pay the poor man's grocery or clothing bills. And doctors who practise this method should logically expect that their chauffeurs and domestic servants, the engineer or architect who builds a house for them, or all who render them service, should charge them on the same principle. The poor who have communicable diseases should, of course, for the protection of the health of the community, be treated free, or isolated, if they cannot or will not provide treatment for themselves. But it is a serious question how far free medical treatment should be carried, and undoubtedly there is much hypocrisy in connection with it. It is all right for the rich to give to the poor if they wish to do so, but it is all wrong for an individual or for the State to force a rich man to give to the poor, directly or indirectly, against his will. When done by the State it is socialism, pure and simple; when done by an individual it is just as bad. Some lawyers, also, are extortionate in their charges because they can take advantage of sentiment in making them.

This may all be summarized by saying that there is much more opportunity for the quack and fakir and charlatan in the medical and legal professions than in the engineering profession. This, however, will hardly be considered a disadvantage of the engineering profession except by a man who wishes to be himself a quack or a fakir.

While it is probably true that the engineer, for reasons which have been explained, cannot to the same extent take advantage of sentiment in making his charges, yet the talk which is sometimes heard among engineers about the disadvantage of the engineer as compared with the lawyer or the physician arises from envy, generated by occasionally hearing of lawyers or doctors who receive very large fees for services requiring but little time. It is the same feeling which leads the union agitator to declaim against capital and the large salaries paid to captains of industry. It does not mean that the engineer has any lower standing, or that his services are any less valuable, measured by a proper standard.

The point is, that the services of the physician or the lawyer are more often personal services than those of the engineer. The engineer, in general, works for the public or the community rather than for the individual. Now, the individual is always more responsive and appreciative than the public. An aristocracy or a small body of men, such as the directors of a corporation, may appreciate services done them or to those they represent, but this will not, in general, be true of a democracy. This is one reason why Public Service in this country is not more attractive to able men. Too often their services, though great, may be unappreciated, and they may be rewarded only by criticism and contumely. Nevertheless, while the "grateful patient" does not exist for the engineer, it is perhaps even a greater satisfaction for him to feel that he is constructing works which add to the convenience and comfort, or even furnish the necessities, for thousands and millions of his fellow men every day.

As a matter of fact, while it is true that the engineer does not generally receive fees as large as those often paid in law or surgery, it is probable that the average earning is as large in civil engineering as in the law or medicine. This statement cannot be proved or disproved, as the writer knows of no available statistics. The lawyer who defends or prosecutes a suit involving millions, or who breaks or sustains a will involving a large estate, may receive an enormous fee, much larger than that ever gained by an engineer, but the average earnings of lawyers are probably moderate. An engineer who puts through a large enterprise generally does so as an employee, on a salary, and if a large profit is made, it is apt to go to the promoter or financier who employs the engineer. But engineering fees are often large, and the willingness to pay such fees is increasing. The writer knows of one fee of $125,000 paid to an engineer, and this is large enough to satisfy most people.*

Some engineers complain that their profession has not the standing of the law and medicine in the public estimation, and that the engineer is not as highly respected or influential as the lawyer. This is certainly untrue, as a general statement. It is a question of the individual. The writer is sure that leading engineers

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* See Judge Baldwin's interesting work in this series, on "The Young Man and the Law," pp. 44-52, in which he says that lawyer's fees are generally overestimated.

have quite as high a standing as any other members of the community. There are, of course, engineers of low standing and low merit; but there are many more lawyers and doctors who are considered beneath contempt. And as to earnings, that should be an entirely subordinate question in any intelligent consideration of the matter of choosing a profession. The main question is as to the opportunities it offers for service, and for the performance of valuable and enduring work, and in these respects engineering is unexcelled by any other field. Let the young man who wishes to become an engineer fully prepare himself for the work, and to meet life's problems, and he need not worry as to whether he will be recognized as he deserves, or as to whether he will be able to support himself. Let the reader reflect on the words of Emerson, quoted as a motto at the beginning of this book.

Nevertheless, it is true that the engineer often does find that his services seem less appreciated than they ought to be, and there are reasons for this, as there are for everything.

One of these reasons is that the engineer is often a narrow man, occupied mainly with the technical details of his profession. He is often not a good mixer, and not apt to be so interested in general affairs, or so conversant with literature, history, art, or music, as men in other walks of life. This is unfortunately a common characteristic of the engineer, but it is his own fault, and partly that of his training, as has been referred to in Chapter IV. There is no necessity for it.

If the engineer concerns himself with technical details entirely, does not mix in society, take part in public affairs, belong to social clubs, or take part in social activities, it is very natural that such a man should come to be regarded as a high-class workman rather than as a highly trained professional man, but this is a question of the individual.

It is also a fact that engineers are often lacking in the power of expression. They often lack the ability to speak easily, forcibly, or correctly in public, and frequently they lack the power to express themselves in writing. This again diminishes the regard in which such a man will be held in popular estimation, but there is no necessity for it. The fact that such conditions exist and that the engineer is often handicapped, shows the necessity of a broader education than the engineer usually receives, and the necessity for self-cultivation in these matters throughout life. This condition of things cannot fairly be considered a disadvantage of the profession. It is probably true, however, that the practice of engineering, dealing as it does with technical details largely, and less with affairs of the day and matters of business than the profession of law, should tend to cultivate in the engineer this lack of breadth.

The engineer is generally a modest man, frequently too modest. He does not assert himself enough. The study of science, the possession of the scientific attitude of mind, the realization of the uncertainties involved in most problems, all tend to cultivate this trait. On the other hand, men who study uncertain subjects like many branches of economics are often the most dogmatic and intellectually arrogant, and such men, though they may be charlatans or bluffers, sometimes make their way for a time and succeed in deceiving people into believing that they are reliable guides.

The engineer is frequently a poor salesman, especially of his own services. This is largely due to his modesty, combined with a frequent lack of business capacity. This again, however, is no fault of the profession. The doctor and the lawyer seem to have no difficulty in learning how to charge for their services. The engineer should learn the same lesson.

It will be seen from the above that most of the disadvantages that have been claimed to exist with reference to civil engineering are disadvantages of the individual, rather than disadvantages of the profession. It has no doubt been true in the past that, taking a college class, a larger proportion of the best and strongest men have gone into law rather than into engineering. It is also still true that it is impossible to make a silk purse out of a sow's ear. If weak men go into the practice of engineering they cannot expect to make any greater success in it than in any other profession. If, however, strong men go into it, men possessing breadth, justifiable self-confidence, a thorough knowledge of principles, character, perseverance, determination, tact, initiative—men who are determined to succeed, and who have business capacity as well as technical knowledge, they will find ample opportunities in the profession, or in the business fields in which a knowledge of civil engineering is perhaps the best preparation for success, or at least as good a preparation as any. The engineer is becoming more and more appreciated. He is being called in as an adviser in economic matters, as a witness in cases before the courts, as a member of public commissions, as an arbitrator, and the popular estimation in which he is held is increasing steadily. There is no reason why the highest offices and the greatest distinction should not be within his reach if he will not insist on staying within his shell. He is being daily more and more recognized as the kind of man competent to form a clear, unbiased and independent judgment on important business matters. Probably the engineer is better appreciated in Europe than he is in this country, though it is difficult to see why this should be the case. In England it is common to pay large fees for engineering services—as a rule, larger than those that are paid in this country.

Reference has been made to the fact that many high executives in our great corporations and in the railroad and business world have begun as civil engineers. This is becoming more and more true in the political world, although here the profession of law still seems to lead most frequently to eminence. George Washington was a surveyor, as was Abraham Lincoln also for a time. President Sadi Carnot, the fourth President of the French Republic, was a civil engineer, trained in the State Engineering School. President Menocal of Cuba was a civil engineer, a graduate of one of our own engineering schools. We all know that Mr. Hoover, Secretary of Commerce in President Harding's Cabinet, is a mining engineer. The writer knows of several instances where engineers have been elected mayors of cities, and they have frequently been members of important public commissions having to do with administrative as well as construction work. City managers, under the plan now so largely in vogue, are generally engineers. The present Governor of Vermont is a mechanical engineer and past President of the American Society of Mechanical Engineers. Nevertheless, it must not be concluded that if a man wants to be mayor, governor, or president, the easiest way is through engineering.

In England, too, great respect is paid to the memory of eminent engineers. Robert Stephenson and Thomas Telford are buried side by side in Westminster Abbey and Lord Kelvin is also buried there. There are also memorial windows to Joseph Locke, Isambard Brunel, Richard Trevithick, Sir Benjamin Baker, Sir William Siemens and Lord Kelvin; and one to the memory of Sir John Wolfe Barry will be placed there shortly. These instances merely show that if the engineer desires to enter public life there is no real obstacle in the way. The work of administering the affairs of a large city involves engineering matters at almost every turn. It also involves legal and business matters, but these latter are no more important, and probably less important, than the engineering matters. There is no reason why the engineer should not acquire a sufficient knowledge of legal procedure and of business affairs, and it is probably easier for him to do this than it is for the lawyer or the business man to acquire a knowledge of engineering matters. Of course, a lawyer as mayor of a city may say that he can hire engineering advice, but it is equally true that an engineer as the mayor of a city could hire legal advice. Much depends upon a man's ability in selecting advisers and in judging men. It is true that as a rule the engineer has not been as close a student of men as the lawyer, and that he has not been as well able to select advisers and to judge of men as the lawyer, but this again is an individual matter and there is no reason why it should be so.

All the above points to the necessity of a broad training for the engineer, and it shows that if capable men enter the profession they will find in it a field for their activities which has almost unlimited possibilities.

CHAPTER VI

THE OUTLOOK FOR THE CIVIL ENGINEER

When it is recognized how wide the field of civil engineering is, how many necessary and constantly expanding fields of human industry it touches, it becomes evident that notwithstanding necessary variations in business activity, the outlook for the civil engineer must be good, and the demand for his services constantly—though not uniformly—increasing. It cannot be otherwise unless the progress of industry is to permanently retrogress. The appreciation of his services, and the compensation paid him, must also increase. There has been a noticeable improvement in this respect in the last few decades. There will, of course, be periods of business depression, when numbers of engineers, as of other men, will be out of employment, but the general trend will be upward. This is particularly so in view of the opportunities that an engineering training offers of engaging in business, in administrative and other positions where engineering knowledge is necessary or desirable, and in view of the fact that the habits of prompt decision, initiative, resource, and ability to meet new conditions—all of which habits should be developed by an engineering education and by engineering experience—are potent elements in success.

This has been recently abundantly and conclusively demonstrated by the events of the Great War. It has been the testimony of practically all Americans who had charge of important departments in that War that the men who had had a technical training made the best showing. Secretary Weeks is reported to have said recently, regarding the War Department, "The records of the department show that of the officers of our armies who served overseas the best results were shown by those who had technical training in addition to their military education." The same is true of the men who did not go overseas, but who had to do with the manifold war activities at home. The selecting of Mr. Hoover as a member of the cabinet of President Harding is a recognition of the same fact.

The day of the engineer is approaching, not only of the civil engineer, but of the engineer in any branch of the profession. The time is coming, and coming rapidly, when it will be generally recognized that the man who can intelligently control and use the forces and materials of nature for the convenience of man is the one who can be depended upon to direct the largest undertakings, and who is perhaps the largest factor in national progress and prosperity.

Mankind has passed through various "ages." The present age is the *age of power*. Almost every human activity, even farming, depends upon the development and application of power. The development and use of power is the function of the engineer—mechanical, electrical, and civil—so that the age of power, now only in its beginnings, must more and more require and recognize the engineer.

Moreover, war is now more a matter of engineering than of anything else. The Great War was a conflict of engineers. No longer do knights in polished armor decide by individual prowess the fate of nations, but wars are won by the side that can best use and direct the forces and materials of nature—unfortunately not for the benefit of man—but for his destruction. We all hope that wars may cease, and that these great agencies of destruction may be turned to other uses; but all this illustrates that the age is one of power—of engineering. The Great War has impressed this fact upon the mind of the coming generation. Young men's minds are now full of thoughts about mechanical appliances. Technical schools are growing faster than schools of arts. What is needed is that the most capable young men of the coming generation should realize the opportunity offered by a technical training.

The saying that you cannot make a silk purse out of a sow's ear, while its literal correctness has been of late disputed and possibly disproved, remains in principle as true as it ever was. You cannot develop from a seed more than the potentialities that are in it. You cannot develop in a man more than the possibilities that are in him. It will some day be recognized that an engineering training is the best preparation for business, and our capable young men will in increasing numbers attend the engineering schools.

Reference has already been made to the fact that in universities where the engineering school has been given adequate support, endowment, and recognition, it has often, if not generally, outstripped the college of "arts and letters," and this will be increasingly the case. Independent technical schools, too, are growing fast, and seem to have, more than the colleges, the confidence and support of the leaders of industry. The latter are more often dependent upon appeals to the loyalty of alumni, while the technical schools more often enlist the interest of industrial leaders of wealth and influence who are not college graduates. The Massachusetts Institute of Technology, little more than fifty years old, is now larger than many universities, and if it could handle properly all the students who would like to go there, it could be as large as it pleased. But size does not necessarily mean efficiency, and this only illustrates the trend of the times.

Our universities should not ignore the handwriting on the wall, and should realize the necessity of filling the great needs of the future in applied science. They must overcome the prejudice in favor of a so-called "culture" which is merely a superficial veneer, without thoroughness or discipline, while doing all they can to promote true culture, combined with discipline, and to bring out the best and highest that is in each student. On the other hand, students of engineering must broaden themselves beyond the narrow limits of their professional studies, and qualify themselves to deal with the great problems of the day, to use the mother tongue correctly, to gain acquaintance with other languages and literatures, and with the thoughts and deeds of great men.

Statistics are very unreliable, unless one knows how they are obtained, what they include and what they exclude, but the following may be given. In 1880 and in 1910 the numbers of practitioners in three professions were, according to the United States Census:

	1880	1910
Civil Engineers and Surveyors	8,261	58,963
Lawyers	64,137	114,704
Physicians and Surgeons	85,671	151,132

The number of engineers in 1910 includes mining engineers, but it is probable that there were few mining engineers in 1880, so that the figures may be comparable. From these it follows that the increase in civil-engineers in 30 years has been 613 per cent., of lawyers 79 per cent., of physicians and surgeons 78 per cent. In reality, the growth in numbers of engineers has probably been even greater: for while every lawyer or physician has probably been correctly registered, there are no doubt many men who are really civil engineers by training, but who occupied administrative or other business positions in 1910, and were not registered as engineers.

Similar results are shown by every other comparison that the writer has made. For instance, the growth of engineering students in some of our colleges is indicated by the following table:

	1880-81	1920-21	Per cent. increase
Number of students in Civil and Sanitary Engineeering Dept. of the Mass. Inst. of Technology	14	392	2,700
Total number of students in the Mass. Inst. of Technology	335	3,436	926
Number of students in the Rensselaer Polytechnic Inst.	104	1,093	951
Number of students in the Harvard Medical School	241	439	82
Number of students in the Harvard Law School	156	944	505

Another measure is afforded by the growth of engineering societies, as shown by the following table. Comparisons between the different societies must not be too closely drawn, because of differences in entrance requirements, "drives" for increasing the membership (of which there have been none in the Society of Civil Engineers), etc.

MEMBERSHIP IN
AMERICAN SOCIETY OF CIVIL ENGINEERS
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
AMERICAN SOCIETY OF MECHANICAL ENGINEERS
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
1870-1920

	Civil	Mining	Mechanical	Electrical
1870	243	....	.....	.....
80	601	829	.....	.....
90	1,296	1,961	1,029	488
1900	2,199	2,748	1,951	1,224
10	5,292	3,874	3,832	6,719
20	9,907	9,307	13,173	10,692

The engineering problems presented for solution by the engineer are increasing, not only in number, but in magnitude and importance. Within a few years, Boston, New York, and Los Angeles, as well as many other cities, have had to provide new supplies of water. Others have had to enlarge or modify their methods of disposing of sewage, and rendering it innocuous.

In the new water supply for New York, there were at one time 303 engineers of the higher grades employed, and 471 engineering assistants, draughtsmen, inspectors, rodmen, etc. The amount expended on this work to August, 1921, was $146,606,000, the contract work in progress was estimated at $16,278,000, and the additional amount necessary to complete the work was $16,000,000; making a total cost in round numbers, of $180,000,000. The plan and estimate for this project were prepared within a space of time of five weeks, following the preliminary studies, and the original plan has been adhered to with but slight modifications. The total sum of $180,000,000 is only $3,000,000 in excess of the original estimate, notwithstanding the fact that from 1916 to date there has been a material increase in prices, but for which the whole work would be completed well within the original estimate. This is a remarkable record, and reflects great credit upon the Chief Engineer, Mr. J. Waldo Smith, and the engineering staff. This work delivers to New York an additional supply of over 300,000,000 gallons daily, from the Catskill Mountains. The maximum number of employees of the Board of Water Supply at any time was 1,757, and the maximum contractors' forces about 17,000. In addition, many men were engaged in manufactories, specially on this work, bringing the grand total to about 25,000. This work stands "in a class by itself, and no other aqueduct, ancient or modern, approaches it in size and capacity." It has been termed "the greatest system of municipal water works in all the world."

In a similar class stands the great system of subways and elevated lines providing transportation in New York City. "When this work was at its peak, in 1915 and 1916, the contractors' forces numbered about 20,000 men, and the maximum force, of all grades, employed by the Engineering Department, was 2,127 in December 1915." At the end of 1920 there was in use "a total track mileage of elevated and subway lines of 601.2 miles out of the total of 618.7 miles embraced in the entire Dual Rapid Transit System." "Expenditures by the city and the operating companies for construction and equipment under the dual contracts and related certificates signed in 1913, have been approximately $435,000,000, including outlays provided for on the work completed or nearing completion." Great as has been the expenditure for the New York Water Supply, the above cost of rapid transit lines has been nearly 2½ times as great,—and all since 1913. And this, of course, does not include the Pennsylvania Railroad tunnel, the Hudson and Manhattan tubes, or the connection between the Pennsylvania and the New Haven lines, over Long Island and across Hell Gate.

Many engineers are employed in valuation work. In the valuation of the railroads of the United States by the Interstate Commerce Commission, the greatest number of engineers was in 1919, when the total number, including clerical forces associated with the engineers, was 1,400. In August, 1921, the number was 325, as the work is approaching completion.

Examples of this kind might be multiplied indefinitely if desired. Mention of some of the large projects of recent years has been made in preceding chapters.

In 1913, a committee of the Am. Soc. C. E. was appointed to investigate the conditions of employment of, and compensation of, civil engineers. This committee received only 6,378 available replies to its questions, and it appeared that after one year of experience the average compensation was $1,187, and the maximum $2,000; after two years the maximum was $5,000; after 5 years the average was $1,935, the maximum $12,000; after 18 years the average was $5,181, the maximum $150,000. It also appeared that the average yearly compensation of 4,529 graduates of technical schools was $3,982, and of 1,829 non-graduates, $3,993. Figures of this kind are of little value, because of the small number of cases and for other reasons, but it does appear clearly that civil engineering offers abundant opportunity for able men. While the average compensation appears low, we have no figures of the average earnings of the lawyer or physician, and it may be doubted if they are higher. It is probable that the young engineer reaches a self-sustaining position, where he is able to support himself and his family, much sooner than the average lawyer or physician. Further, comparisons of this kind take no account of native ability. For the average engineer to complain because the brilliant lawyer or surgeon receives much higher fees, is, of course, only a manifestation of that most undesirable human passion, envy. The real question is as to the comparative opportunities for service, and the comparative remuneration, for men of equal ability and character. This is why the writer maintains that the opportunities offered in engineering are good, and increasing in attractiveness, and that what is needed is to induce greater numbers of capable young men, of good character, to enter the profession. In thinking of compensation, too, it should be remembered that the salary of the Chief Justice of the United States Supreme Court, the highest judicial position in America, is $15,000. And as illustrating inevitable discrepancies in other fields, it may be mentioned that while the Ambassador of the United States at the Court of St. James receives $17,500 per annum, the British Ambassador at Washington receives £20,000 per annum, and his house.

Comparisons are dangerous, and often unprofitable and merely provocative of discontent. The main points to be kept in mind are that a man's success depends mainly upon himself; that money is not the true measure of success; and that civil engineering is a vocation that is healthy, free from many of the worries that harass the lawyer, physician, or business man, and which offers abundant opportunity for creative effort, and for constructing works that conduce each day to the comfort and convenience, and supply the necessities, of great numbers of our fellow men.

Lord Bacon said:

> "There be three things which make a nation great and prosperous: a fertile soil, busy workshops, and the easy conveyance of men and commodities from one place to another."

The last two of these requisites constitute distinctly the field of the engineer, and even the utilization of a fertile soil is largely dependent upon his activity, through irrigation, drainage, and other engineering functions. Even Lord Bacon, therefore, must have recognized in his day that the engineer was the main factor in making a nation great and prosperous.

CHAPTER VII

CONCLUDING SUGGESTIONS

LITTLE remains except to offer some concluding suggestions to young men who may be contemplating following the profession of civil engineering.

Study yourself thoroughly before deciding upon any career, and get the advice of those who know your habits of mind and your peculiarities, and who can judge of your fitness. Remember that there are few men who will fit but one narrow occupation, but that most men would do equally well in any one of several. There are of course certain occupations which differ so radically from certain others, that a man fitted for the former would lack the qualities requisite for the latter; and some men are so peculiarly constituted that they are fitted for but one niche in life. Such men, however, are in the writer's opinion rare. Even the artistic temperament is not inconsistent with ability in engineering. F. Hopkinson Smith was not only a good engineer, but a delightful writer, and an artist of distinction; and the writer knows another distinguished engineer who would certainly have made a success as an artist; and several artists who were trained as engineers, and who lose no opportunity to express their sense of obligation to such training. The writer also knows several clergymen who were trained as engineers, one of whom practiced engineering for some years; and a number of lawyers who had the same training and experience. But chance, or fate, or choice will generally soon determine a man's career, and then he must specialize; and there are few who, like Hopkinson Smith, can practice more than one occupation.

Having determined upon civil engineering as a career, train yourself by practicing the qualities that will make you successful. Read the biographies of engineers and the history of engineering, and learn the difficulties that have beset engineers and the manner in which they have been surmounted. Above all, observe the qualities—of mind, body and character—which are requisite, and develop them by daily exercise.

Train yourself in observation and in the habit of quick decision. If two men walk down the street together, one may see much more than the other. One may be habitually immersed in thought, and may see little: and while the engineer must think, this habit, which prevents observation, is not a good one if carried too far. The game which sometimes played, by which each person is allowed a short time to look at a table on which are a number of objects and is then required to make a list of what he saw, is good for developing this faculty. Visual testimony is often quite erroneous. If a man swears that he saw a thing happen, that does not prove that it did happen. For this reason, the writer likes to see sleight of hand exhibitions, which make him realize that seeing is not believing, and that the testimony of the senses is not always reliable.

Remember that engineering is practical, not abstract, and is more common-sense than anything else. Do not let anything train the common-sense out of you. Think before you ask a question, so that you will not ask a fool question; and see first if you cannot answer it yourself. Train yourself in estimating distances and quantities, and to measure distances by pacing. If you see a big boulder in a field, try to estimate what it weighs; then measure it approximately and see how near you came.

Pick up all sorts of scraps of information that may help you, and keep a note book or a card catalogue in which you record them. The cost of work, the number of men employed on a job, the time it took to complete it, all may be useful at some time; and such data, from personal experience, will always command more respect than quotations from books.

Train yourself in mental arithmetic, and so learn to get results quickly without pencil and paper. The judgment of some men, regarding such things as the quantity of earthwork on a line of railroad, or the value of property, is sometimes of greater value and accuracy than the results of long calculations, and sometimes there is not time or opportunity to perform the latter.

Do not be discouraged if you cannot get an education in college or technical school. Remember that many of the most eminent engineers had none. The lack of it will be a handicap to you for a time, provided that you could really profit by it; but make up your mind to turn that stumbling block into a stepping stone, and that by being obliged to get this knowledge and training under difficulties you will get it more thoroughly. But do not deceive yourself and stubbornly persist in thinking you can be a successful engineer when you really have not a scientific mind. Do not think that because you have always been interested in locomotives or automobiles, or played with mechanical toys, or plastered your room with pictures from the *Scientific American,* you are cut out for an engineer. Remember that engineering is a science, and that to succeed in it you must master the fundamental principles of chemistry, physics, mathematics and mechanics, and the properties of materials. If you cannot do this, you may be a good mechanic, or you may even be a good administrator or business man, but you will not be an engineer.

Learn above all things, whether you go to college or not, how to study, so that you can take up a new subject and master it yourself. You will very likely be helped in doing this by the writer's pamphlet, "How to Study," published by McGraw, Hill & Co., which you should read and reread until you have absorbed its atmosphere. Let your studies, especially of mathematics, be concrete, not abstract, and scrutinize carefully the data or assumptions upon which a theory rests. Do not let your mind go to sleep over algebraical formulæ, but translate them into practical results which can be expressed in words. Systematize and arrange your knowledge. When you are studying a subject, get the fundamental principles, and let them be like the trunk and main branches of a tree, upon which you can hang all subordinate principles or facts, each in its proper place.

Do not get the habit of seeking the easy way by evading difficulties, but accustom yourself to surmount them. This does not mean that you should make difficulties, or pursue complicated or abstruse methods where an easy or obvious one will give the same result. This is often done in mathematics, and is vicious. Where an easy way will lead to the result, it should, of course, be chosen; for there is abundant opportunity to cope with difficulties without creating them. But do not evade them; and, in college, choose subjects of study that will tax and develop your powers rather than those which make little demand on them, as so many students do. Under the elective system the writer knows of college students who have selected schemes of study requiring nominally only 25 to 30 hours a week; or which required no work in the afternoon, or nothing before ten o'clock in the morning. Think of it!—an able-bodied young man, faced with greater opportunities than he will ever have again, to afford him which parents or relatives at home are perhaps denying themselves comforts that they need, deliberately trying to do as little as would "put it over" or pull him through! For such an attitude parents are often more to blame than the students or college authorities, some of such parents objecting if their sons are made to work hard, and being more desirous that they should become prominent in athletics or in the social clubs. It may be true, as Emerson says, that "You send your child to the schoolmaster: but 'tis the schoolboys who educate him": but that does not mean that they should not exert themselves to learn as much as they can from their schoolmaster, and seize every opportunity to develop their powers.

To make one suggestion regarding personal habits, the writer strongly advises young men in college or in engineering, not to smoke during working hours. The writer is a smoker, but he did not smoke at all until after he was thirty-five. Many successful engineers are great smokers and many do not smoke at all. If you must smoke, do it at home in the evening. During working hours your time and your best efforts belong to your employer, and your efficiency will be diminished if you smoke. Some engineering offices and industrial establishments do not allow smoking during working hours, and that is right. The same principles are true about work in college, and the student will do best for himself by not smoking at all. But unfortunately the idea often prevails that a boy does not become a man until he smokes, and many college students like to make believe they are men as early as possible.

When you graduate from college and look for a job, be willing to begin at the bottom, at small wages, and to do anything that is useful. Have no high-flown ideas about what is dignified. All labor is dignified; it is loafing that is undignified. Do not think that because you have a diploma you can begin at or near the top.

Remember that a diploma does not *guarantee* a single good quality: a man may be lazy, or incompetent, or dishonest, and yet possess one. Much depends upon the college and its standards, but the above statement is true for all. All the diploma shows is that its possessor managed to do enough, and well enough, to get it. It may, therefore, mean a certain amount of competence, but the standard, even in our best colleges and technical schools, is low compared with that which an ambitious young man should have for himself. When you go to work, you should begin at the bottom, in overalls or at a desk or draughting table. For some time you will not be worth anything to your employer, except in manual labor, for you must learn his business and his methods. You must expect to work under young men of your own age who did not go to college. They have something that you have not, namely, experience; but if you have things—principles and knowledge and mental training—that they have not, you may expect, as you gain experience,—other things equal,—to pass them in the race, unless they can gain the things that you got in college faster than you can gain the experience. It is surprising how many college graduates think themselves qualified to begin at the top, because they have been studying books or listening to lectures; and that it is unworthy of their education for them to work under men of their own age who have not been to college. Even the schools sometimes foster the idea that they can prepare young men to begin as "managers" or administrators, omitting the routine of experience. It is a fallacy. It cannot be done. There is routine and drudgery in every occupation. You must be able to perform it cheerfully, uncomplainingly, and well.

The young man taking a job should be willing to do anything, and when he has finished one piece of work should ask for another, not wait till it is brought to him; and he should not watch the clock. The writer once sent two young men from the same class to work in the same office. One strove to do all he could; when one job was finished he asked for another, and he stayed after hours if by doing so he could help his employer. He rose to the highest position in the concern. The other had his eye on the clock, stopped promptly when the bell rang, and when he finished one job read a newspaper till he was told to do something else. When the first man had reached nearly the highest round of the ladder, the second was not far beyond where he started.

I would strongly advise young men in college to work summers. A healthy boy of eighteen or twenty does not need to loaf three or four months each summer at a resort. A few weeks' vacation should be enough, and during the remaining time he may be gaining experience, and perhaps getting a foothold in some concern that will take him permanently after he graduates. He will appreciate his studies better if he sees their application. This principle of coöperative work between the schools and the industries has led, of recent years, to systematic curricula in which the student spends alternate periods in the school and in the industry, with only a few weeks of vacation in the year. This plan has met with great success at the Universities of Cincinnati and Pittsburgh, and has recently been put into operation at Harvard University.

The young engineer, with all his zeal for mental and material progress, should not neglect his moral and spiritual development. He should bear in mind that his profession is one directed to the benefit of mankind. He should study men, learn how to deal with them and direct them, how to get the best work from them, and by a human and sympathetic attitude toward their problems and their points of view, gain their cooperation and esteem. Engineering has to do with men as well as materials, and it is as important to know how to deal with one as with the other.

Many professional societies have adopted codes or canons of ethics as guides for the conduct of their members. The Massachusetts Medical Society has a short code of seven paragraphs. The American Bar Association has given much consideration to this subject. A committee of this Association submitted an interesting report in 1907 containing a compilation of the codes of ethics adopted by the various state bar associations, and also containing Hoffman's fifty resolutions in regard to professional deportment, which were framed by David Hoffman, of the Baltimore Bar, for adoption by his students on admission to the bar "as guides never to be departed from and to which they will ever be faithful." The Association adopted in

1908 a set of canons dealing with the responsibilities and duties of lawyers and their professional conduct, with an oath of admission requiring the observance of the highest moral principles. It may be remarked that there is perhaps more need for such a code in the legal profession than in others. George Sharswood, the author of "An Essay on Professional Ethics," referring to the legal profession, made the following statement:

> "There is certainly, without any exception, no profession in which so many temptations beset the path to swerve from the line of strict integrity, in which so many delicate and difficult questions of duty are continually arising. There are pitfalls and mantraps at every step, and the mere youth, at the very outset of his career, needs often the prudence and self-denial as well as the moral courage, which belong commonly to riper years. High moral principle is the only safe guide, the only torch to light his way amidst darkness and obstruction."

It is well to have such a code, and yet, when all is said and done, if a man has not the principles of morality in his soul, such a code will not hold him up to the highest moral standard, though it may give ground for punishment or for disbarring him from practice if he violates its canons.

Architects and engineers have adopted codes of ethics, but they are generally short and do not attempt to go into all the details of what an engineer should or should not do. The code of the American Society of Civil Engineers is as follows:

CODE OF ETHICS
of the
American Society of Civil Engineers

It shall be considered unprofessional and inconsistent with honorable and dignified bearing for any member of the American Society of Civil Engineers:

1. To act for his clients in professional matters otherwise than as a faithful agent or trustee, or to accept any remuneration other than his stated charges for services rendered his clients.
2. To attempt to injure falsely or maliciously, directly or indirectly, the professional reputation, prospects, or business, of another Engineer.
3. To attempt to supplant another Engineer after definite steps have been taken toward his employment.
4. To compete with another Engineer for employment on the basis of professional charges, by reducing his usual charges and in this manner attempting to underbid after being informed of the charges named by another.
5. To review the work of another Engineer for the same client, except with the knowledge or consent of such Engineer, or unless the connection of such Engineer with the work has been terminated.
6. To advertise in self-laudatory language, or in any other manner derogatory to the dignity of the Profession.

Much is said in these days about ideals, and we are urged to form them in the mind and try to realize them in fact. That is well if the ideals—or aims, as they should be called—are good, and possible of attainment. But great harm may be done by forming in the mind an imaginary ideal, without a study of facts, and then striving to reach it. There are great dangers in the pursuit of impractical ideals. After study of the facts of a problem or a situation, such as the engineer is accustomed to make, it may be decided what is best to do under the circumstances. Canon Kingsley said: "The only way to regenerate the world is to do the duty that lies nearest." But there is one aim that the young engineer may and should steadily and unfalteringly aim for, and that is to improve his own personal character. This aim or ideal may well be that expressed in the following verses:

"I would be true, for there are those who trust me;
I would be pure, for there are those who care:
I would be strong, for there is much to suffer;
I would be brave, for there is much to dare:
I would be friend to all—the foe, the friendless;
I would be giver, and forget the gift:
I would be humble, for I know my weakness:
I would look up, and laugh, and love, and lift."

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